Comparison of functional and optical properties of Indirect laryngoscopes relative to the Macintosh laryngoscope

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Contents

Abstract

Dr Seema Charters: Comparison of functional and optical properties of Indirect laryngoscopes relative to the Macintosh laryngoscope

Indirect laryngoscopes allow transmission of the view from the tip of the device to a camera or video monitor via an optical system. At the start of this thesis there was no systematic way of assessing how they work and how they should be compared. The Macintosh laryngoscope is still almost universally used in the UK, and most of the world, but even the details of how this device works are not generally agreed. Here the starting point was a published mathematical "JIST" model describing the limitations of the Macintosh blade relative to the need for tongue displacement and the space into which it can be accommodated in order to achieve a view of the larynx. This property was considered to describe the Macintosh "functionality".

Unlike Macintosh, the indirect laryngoscopes have optical systems and in the first part of this thesis a bench test was used to examine the "field of vision" that characterises their optics. The devices included were: Glidescope, Truview and Airtraq. The first two of these are "steering" devices because the operator needs to direct the tracheal tube into the laryngeal view whereas Airtraq is a "channel" device because the tube is directed into the view by its channel. Bench studies showed that Truview had the smallest and Airtraq the largest field of vision. In addition there was a requirement for all these devices to be at right angles to the inlet target otherwise the images became progressively distorted.

Next a simulation study using the AirSim manikin was performed to observe the conditions needed to produce the "peardrop effect" (as predicted by the JIST model) for Macintosh and all the study blades. This occurred with all the blades when the conditions were difficult. Airtraq was the only blade which had a different profile in that "peardrop" occurred late and with less force needed. A further simulation study involved creating a novel test-bed of progressive difficulty for Macintosh laryngoscopy in a Laerdal SimMan based on the notion of reduced space for tongue displacement. These two simulations tested what came to be called "Mac-alike" functionality. For the latter study Glidescope and to some extent Truview proved to be "Mac-alike" whereas Airtraq was different because better views were obtained in the most difficult setting, and as in the AirSim study, less force was needed.

For the final clinical study a novel overlay technique was used taking lateral photographs at the moment of laryngoscopy to define the parameters relevant to the JIST model and the position of the laryngoscope blades in the airway. This study successfully confirmed the peardrop effect as the main limitation of Macintosh in normal clinical use. In other words, normal efficacy depends on tongue size versus space for its accommodation. This was very evident using a novel method of analysis describing the areas on the overlays relevant to the JIST model. The overall "inevitable residual volume" of the tongue (that not displaced to one side during laryngoscopy) was no different for Macintosh, Glidescope and Truview. In that sense they all attempt to deal with the tongue/space problem in more or less the same way. On the other hand Airtraq, was unique in showing that the view did not depend on the tongue size versus space match. Furthermore the position for the viewing "eye" optimized this advantage by allowing a larger volume of tongue to be accommodated by the blade above this "eye" position.

Acknowledgements

I would like to express my sincere gratitude to all the patients who so kindly consented to take part in the clinical study.

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The Glidescope Video Laryngoscope was loaned for the duration of all the trials involved in this thesis by Verathon Medical.

Special thanks to my children Deven and Nikhil for their help, patience and encouragement. Their humour went a long way while preparing this thesis.

I want to thank my brother Sanjay and his wife Shubhangi and my friend Vandana for being there for me at all times.

I would like to remember here my late dad (an amateur astrologer) who always had predicted that I would pursue an interest in research. I want to thank my late mum too for her constant support and my weekly conversations with her had always been my source of strength. I wish they both were here to see this document and I would like to dedicate the work to their memory.

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Section 1 Indirect Laryngoscopes

1.1 Introduction

Prediction of difficult direct laryngoscopy has been addressed by several anatomical, radiological, clinical tests and indices.[1-6] However, most tests in isolation have poor sensitivity and predictive ability.[7-9] Rose and Cohen looked at airway problems in over 18,500 adult non-obstetrical patients. Conventional direct laryngoscopy (DL) was the first choice in 98% of the time. Among these patients, the failure rate was 0.3% and 'awkward' or 'difficult' in 2.5% and 1.8% respectively. More than 3 laryngoscopies were needed in 0.4% patients with DL.[10] Percentage of difficult direct laryngoscopy in Maxillo-Facial surgical patients is reported to be 15% [11] and in cervical spine surgical patients its reported to be 20 %.[12] Such difficulties, even if ultimately overcome can result in significant morbidity in the form of oxygen desaturations and trauma to airway structures due to repeated attempts at laryngoscopy and use of a bougie.[10, 13] Most importantly such blind attempts at passage of tracheal tube or bougie will be unseen at the time and the consequences will only become apparent subsequently.[14, 15]

Over the years a number of attempts have been made to address the above problems related to difficult laryngoscopy with the Macintosh blade. Indirect laryngoscopy aims to improve upon direct laryngoscopy by incorporation of optical system in intubation devices such as rigid blades, endotracheal tubes and rigid stylets. These allow indirect visualisation of the glottis by effectively moving the viewing eye close to the tip of the device and then transmitting the image to a monitor screen. The reported advantages include - improved glottic view, increased first attempt success rate of intubation by novices, simultaneous viewing by teacher and student (thus accelerating the learning of laryngoscopy), capture of images for use in research and documentation for medico-legal use. [16-20] On the other hand new problems have been reported including increased intubation times despite a good view, palato-pharyngeal injury and need for optimization maneuvers to achieve intubation.[21-28]

The advances in this field have concentrated on optical improvements but functional modifications (i.e. alterations in blade shape) have been introduced at the same time without obvious scientific justification. Because these have occurred simultaneously, it has proved difficult to determine whether these functional modifications in their own right are better, worse or irrelevant. Anaesthetists therefore need to be convinced that any optical improvement is not at the cost of a worse "functional" design. This research aims to investigate these issues. Indirect devices that were studied in this thesis are- Truview EVO2™ (Truphatek Int. Ltd; Netanya, Israel), Glidescope® (Verathon Medical; Buckinghamshire UK) and Airtraq® (Prodol Meditec S.A; Vizcaya, Spain)

Aims:

1. Define the relevant field of vision for each of these devices
2. Describe the effect of altered blade alignments on projected FOV images

3. Study functional characteristics relative to the Macintosh blade (i.e. Mac-alike properties)
4. Define Macintosh limitations (i.e. Peardrop effect)
5. Compare devices by blade alignment relative to the glottic inlet
6. Evaluate performance of these devices in simulation for progressive difficulty
7. Evaluate IDLs in a clinical trial to compare functional versus optical advantages relative to Macintosh

1.2 Historical perspective

The Macintosh laryngoscope has been described as 'the most numerously and widely made durable item in the history of anaesthesia'.[29] Sir Robert Macintosh designed this laryngoscope in 1943 primarily to intubate un-paralysed patients. The design was a result of incidental view of the vocal cords observed after insertion of a Boyle-Davis gag for tonsillectomy.[30] Macintosh added the gag shape onto a laryngoscope handle, although he later observed that, in his view, its success was related more to the technique of placing the blade tip into the vallecula to expose cords rather than the actual curve of the laryngoscope blade. Although the title "Macintosh" is given to many curved blade shapes they are not necessarily the same, indeed there was never any engineering specification of his original. Even from the early stages, it was clear that there were limitations with this design because suboptimal or no view was obtained in certain anatomically difficult patients i.e. patients with receding mandible or with protruding incisors. Shape modifications were tried to address this problem.[31, [32)]Attempts were then made to convert Macintosh into an indirect device by addition of optical elements to the curved blade.

Siker laryngoscope

In 1956 Ephraim Siker (Cardiff, Wales, UK) introduced a new angulated, straight blade incorporating a mirror for indirect laryngoscopy. Since the mirror inverted the reflected image, it required considerable experience for both viewing and working with structures in an inverted image.[(33)]

Figure 1 The Siker laryngoscope

Huffman prism

In 1971, Huffman and Elam (Chicago, Illinois, USA) described a modification of the Macintosh laryngoscope blade with a clip-on Plexiglas prism to permit indirect laryngoscopy.[(34)] This prism gave a refraction of 30 degrees in the direction of the larynx and 20 degrees to the left of midline. As such this was the first attempt at bending light to "see around the corner". The main disadvantages were fogging and difficulty with directing the tracheal tube into the field of vision.

Figure 2 Huffman Prism

The idea of using a prism was then enlarged upon with the introduction of the Bellhouse angulated laryngoscope

Bellhouse Laryngoscope

In 1988, Bellhouse (New South Wales, Australia) reported on an angulated, straight blade for routine and difficult laryngoscopy.[35]This instrument was probably the first laryngoscope design on scientific principles in that it was based on his earlier studies in patients with a history of difficulty intubation.[36]It was essentially a straight blade with 45 degrees angle at the midpoint. The horizontal spatula has a small horizontal step and a vertical component that is significantly lower than that in Macintosh blade. The instrument was unusual in being available in 3 adult sizes the differences were the length of the distal straight segments- 6.7 cm, 8 cm and 9.3 cms. Bellhouse suggested that the best exposure of the larynx was obtained using the longest blade possible. In addition he felt that the use of single angle and provision of 3 sizes allowed closer fitting with less risk of failing to insert the instrument when restricted mouth opening or restricted head extension reduced intraoral space.

Bellhouse later added a prism because he realised that the angle could itself obscure the laryngeal view like Macintosh blade whereas addition of a prism would allow for "seeing around the corner". His prism was made from transparent acrylic material and it was positioned with its flat base fitted flush to the surface and the refractive edge abutting against the blade angle. A view of the larynx is obtained by looking through the rear face of the prism. The image obtained via prism is refracted 34 degrees. This requires the operator's head to be further forward than when no prism is used. A curved stylet was recommended to direct tube tip anteriorly. Bellhouse had communicated with Dr P Charters (Liverpool) about the problem of getting tube into the field of vision when using the prism, and it was suggested that this would be achieved with a curved stylet specifically matching the blade shape.

Bellhouse reported successful use of his laryngoscope in 3500 intubations, in 12 of these a Macintosh blade had failed to expose larynx. Comparison of the Belscope blade with Macintosh in studies using medical students as operators, failed to show any advantage for Belscope. Intubation times were prolonged and there was unexpected increased incidence of failed intubations with the Belscope.[37]

Recent developments have expanded this idea further with a new generation of optical laryngoscopes with either complex lens/ prism systems or fibre-optic technology.

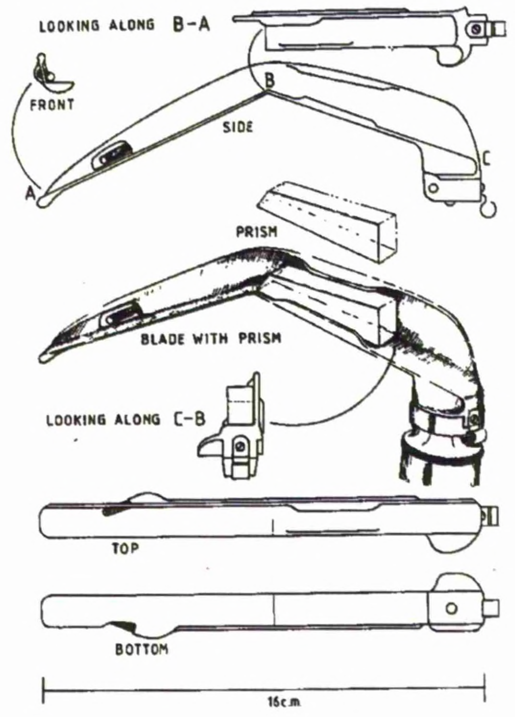

Figure 3 Bellhouse laryngoscope

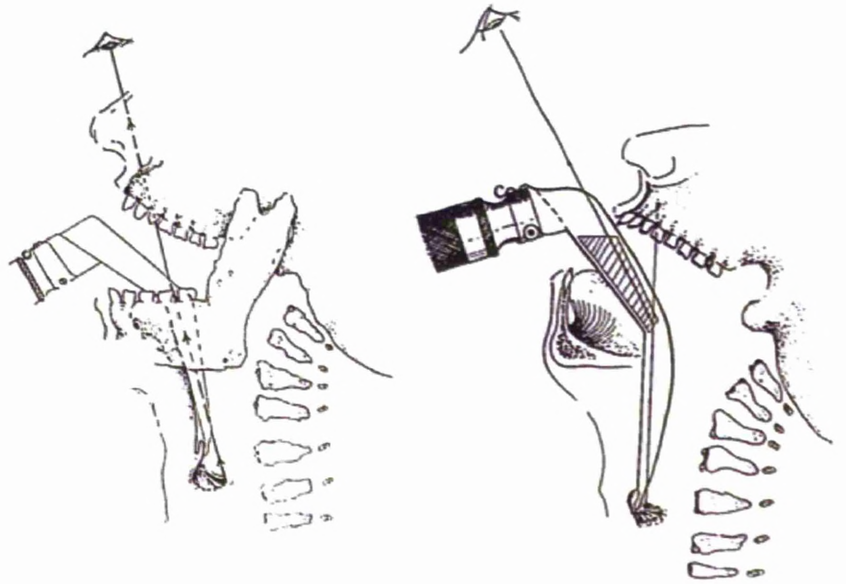

Figure 4 Belscope positioned in the airway.

The left insert shows normal use, looking down the right side of the maxilla. In the right insert a prism is attached for an indirect view.

1.3 Classification of indirect viewing devices

Indirect viewing devices incorporate an optical system, which could be a simple addition of mirrors or prisms or a complex combination of lens and prisms or fibreoptic light bundles. Classification of these devices is important to understand differences in their working. A recent quantitative review of these devices has classified them as either "Bladed laryngoscopes, Optical bougies or Conduits".[38]

1. Bladed laryngoscopes -
    - Blade deformers- Flexiblade, McCoy, McMorrow.
    - Light benders- Bullard, Glidescope, McGrath, Macintosh videolaryngoscope, Truview/Viewmax, Upsherscope, Wuscope
2. Optical bougies- Bonfils. Shikani
3. Conduits- Airtraq, C-Trach

An alternative new classification is suggested for rigid laryngoscopes based on how the tracheal tube is delivered into the field of vision. The direct laryngoscopes have an open path system for tube delivery. i.e. the tracheal tube is passed without any directing channel. They can be straight, angled or curved. The indirect are divided into devices having similar open path tube delivery system, para-tubal (via a channel housing the tube that is parallel to the optical channel) or intra-tubal (where the device and its optics are housed inside the tracheal tube).

Indirect laryngoscopes using open path tube delivery can again be subdivided according to the shape- curved or angled blades. With these devices, the operator directs the tube towards the laryngeal inlet. Glidescope video laryngoscope and Truview EVO2 are examples of these devices and both were evaluated in this thesis.

The laryngoscopes using para-tubal delivery have channel for housing the tube that runs parallel to the optical channel. Tube emergence is determined by the configuration of the tube channel and the tube curvature. Once the tube has emerged it needs to align to the laryngeal inlet and this can create problems with intubation. Airtraq is an example of this type of device and was evaluated in this thesis.

The laryngoscopes using intra-tubal delivery system have optics within the tracheal tube. Thus the tube path closely follows the optics and tube is always in the field of vision. These devices are generally metal stylets and the tongue is a major issue with these devices as the operator, and not the device, has to achieve tongue control by some means.

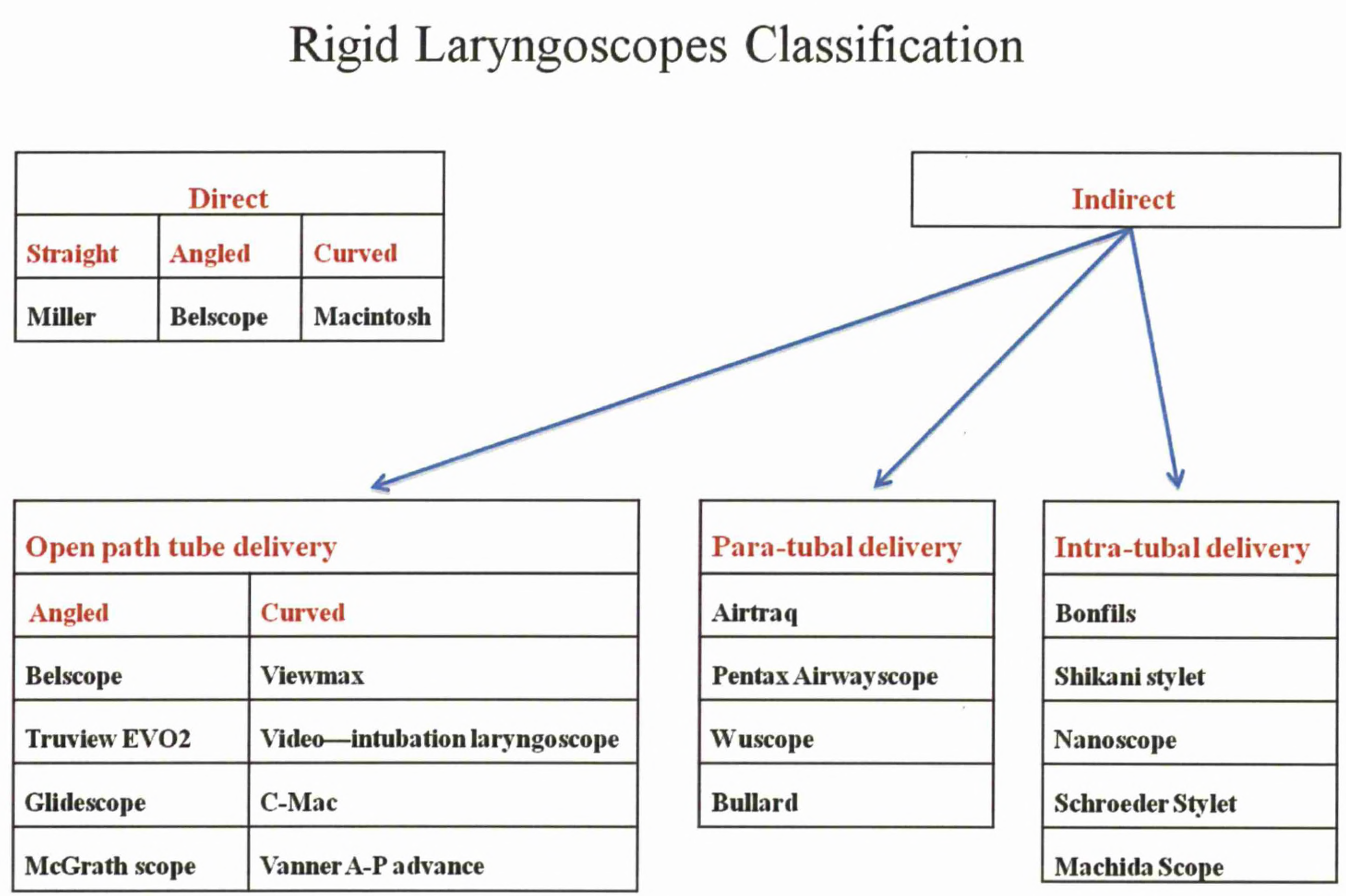

Figure 5 Classification of rigid blades based on tracheal tube delivery

1.4 Indirect Laryngoscopes Studied

For this thesis three indirect laryngoscopes were evaluated in simulation and clinical trials. The choice was based on examples of direct tube delivery (Glidescope and Truview) and para-tubal tube delivery (Airtraq).

The Glidescope® Video Laryngoscope (GVL)

GVL laryngoscope utilises video camera that is embedded into a plastic laryngoscope blade. The blade is 18 mm wide at its maximum width (14 mm in the newer models) and has an angle of 60 degrees at the mid-line. A light emitting diode (LED) solid state light assembly mounted besides the camera provides illumination. The resulting video image is displayed on the supplied 7" display colour monitor that has facility for recording. The video camera in the Glidescope is recessed for protection from bloody and secretary contamination during intubation. The heated lens innovation was the first application of anti-fog built into a video or fibre-optic device. The success of the Glidescope was possible because of unique geometry, the heated lens, the 60 degree blade angulation, the placement of the camera back at the midpoint of the blade, and the wide camera viewing angle of 50 degrees. [39]

Figure 6 Glidescope Video Laryngoscope (GVL) with monitor

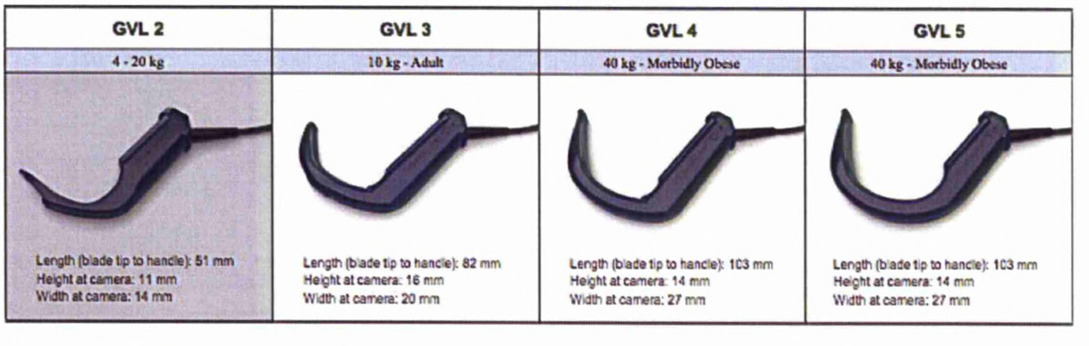

Figure 7 GVL with available blade sizes

GVL 2. 4-20kg, GVL 3, 10kg to adult, GVL 4 and 5 for 40kg to morbidly obese

Gliderite™

This rigid stylet has been designed specifically for use with the Glidescope. The angulation of the stylet conforms to the blade shape providing improved manoeuvrability in tracheal tube placement.

Figure 8 Gliderite-Intubating stylet to aid intubation with Glidescope

Glidescope AVL video laryngoscope (advanced video laryngoscope)

This is a single use version of original product. It eliminates the need for disinfecting the blade. It has a slim Video Baton that houses a high resolution camera with anti-fogging mechanism. The Batons are available in 2 sizes and can be easily inserted into single use blades (stats) that are available in 6 sizes.[40] The blade angulation in these disposable blades is different than that from the original product. This version was not evaluated in this thesis.

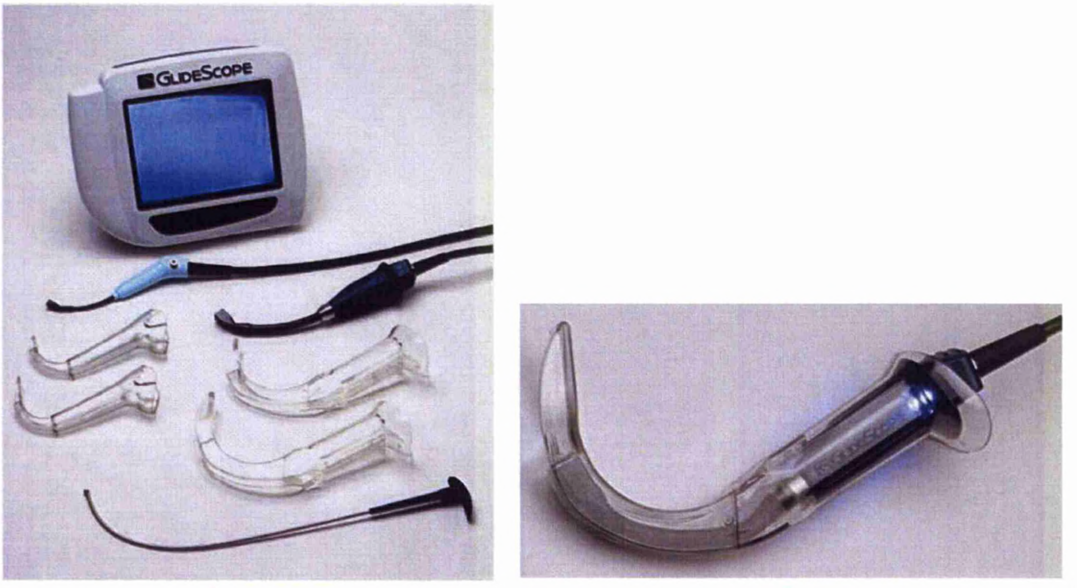

Figure 9 Glidescope AVL system

Component parts and monitor (left) and assembled laryngoscope (right)

Airtraq

The Airtraq® (Prodol Meditec,S.A., Viczaya,Spain) blade consists of two side by side channels. One channel houses the tracheal tube while the other terminates with its distal lens. A battery operated light is present at the tip of the blade. The image is transmitted to the proximal view-finder using a lens/prism complex. It is available in 4 sizes (size 0 to 3, 0 and 1-paediatric size, 2 and 3- adult sizes). The minimum mouth opening required for the insertion of this device is 16mm for an adult. A clip-on wireless video system is available which allows viewing from the Airtraq camera head on an external monitor. A charging dock station for the Airtraq camera is also available with the monitor. [41]

a

b c

Figure 10 Airtraq with optional video system

a. Airtraq with various available sizes (colour coded)

b. Airtraq Wireless monitor

c. Airtraq Video Camera

Truview

The earlier version of this laryngoscope was also called Viewmax (Rusch, Duluth, GA). It was essentially a curvilinear blade that had a view tube with a patented lens system. The lens could refract an image approximately 20 degrees. It was available in adult as well as paediatric size. This now has been modified to a 45 degrees angled blade called Truview EVO2 (Truphatek, Netanya, Israel). The blade incorporates an unmagnified optic side port with anterior refraction of 46 deg in the line of sight. The eyepiece can be connected to a dedicated digital LCD screen or to an endoscopic camera head with a monitor. In addition the blade has a port that connects to the auxillary oxygen supply which prevents misting and clears secretions from the lens. (42)

Figure 11 Truview family of blades

Viewmax, EVO2 small, EVO2 large (from top to bottom)

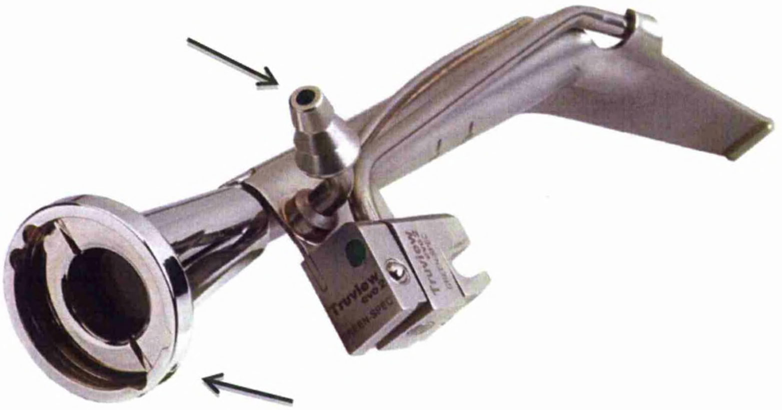

Figure 12 Truview EVO2

Operator view- (Top arrow) O2 port and (bottom arrow) eyepiece

Figure 13 Truview EVO2 with camera attachment

Section 2 Field of Vision

2.1 Introduction

This section initially describes definitions used to describe functional aspects of the study blades. Next Field of Vision (FOV) characteristics of these blades were evaluated in bench studies. FOV for the Truview family of indirect laryngoscopes was compared with the earlier indirect device, Belscope. Airtraq was then studied along with an evaluation of tube delivery from its side channel. Following on from that effect of blade alignment on the FOV was studied for Truview, Glidescope and Airtraq in a bench study.

Definitions

The terms used in this section are defined below:

Distal Straight Segment (DSS):

The distance from the effective viewing position to the blade tip.

Blade angulation:

The angle between the distal straight segment and the rest of the blade.

Field of Vision:

The angle from the distal straight segment to the maximum view away from it.

Blind Spot:

When delivery of tube into field of vision is at least partially blind to the observer.

Presentation screen:

When limitations are imposed on the final image by the manufacturer during its processing. (This is normally minimal and affects the image edges / corners.)

Effective viewing position:

The position from which the lens or prism system first captures the image.

Linearity of viewing system:

The extent to which the image of the object is magnified in a linear sense, i.e. whether the image consists of similar graph paper squares to those on the object source. (This may apply only under certain conditions, as for example when the object source is at 90 degrees to the distal straight segment.)

Blade alignment:

The angle the distal straight segment makes relative to the plane of the object of interest.

The laryngoscopes studied in this thesis had the following dimensions-

Belscope	Blade angulation- 45deg	DSS-9.7cm
Glidescope (GVL)	Blade angulation-60deg	DSS- 5.5cm
Airtraq	Blade angulation -curved	DSS- 3.8cm
Truview Viewmax	Blade angulation - curved	DSS- 4.7cm
Small EVO2	Blade angulation - 45 deg	DSS- 3.9 cm
Large EVO2	Blade angulation -45 deg	DSS- 5.5 cm

2.2 Field of Vision

The first bench work to compare Field of vision was for Truview laryngoscopes and the Belscope Laryngoscope. (This was presented at Anaesthetic Research Society meeting in Dundee in June 2006 and published as, Br J Anaesth 2006; 97 (3): 434)

Field of Vision (FOV) is measure of angle from the nearest possible view of the blade tip to maximum view away from it. Measurement of this angle allows comparison of "view" which is independent of the length of the distal straight segment. The Truview laryngoscope is claimed to have an improved "Field of View" by increasing the refraction angle (for Truview EVO2 it is 46 deg.).[42]

Figure 14 Trview EVO2 (top) and Belscope (bottom)

We compared the Field Of Vision (FOV) of the Truview family of laryngoscopes and the Belscope laryngoscope, as these have similar blade angulations but different distal straight segments (figure 11). As explained in Section 1.4, the earlier version of

Truview (Viewmax) had a curvilinear shaped blade with a lens refraction of about 22 degrees. The newer version, EVO2 has a blade angulation of 45 degrees in the blade and a refraction angle of 46 degrees. As explained earlier in Section 2 the distal straight segments were 4.7 cm for Truview Viewmax, 3.9 cm for small Truview EVO2 and 5.5 cm for the large Truview EVO2. Belscope laryngoscopes have a 45 degrees angulation at midpoint of the blade. It was available in 3 sizes based on the differences in length of distal straight segments- 6.7 cm, 8 cm and 9.3 cms. [35]

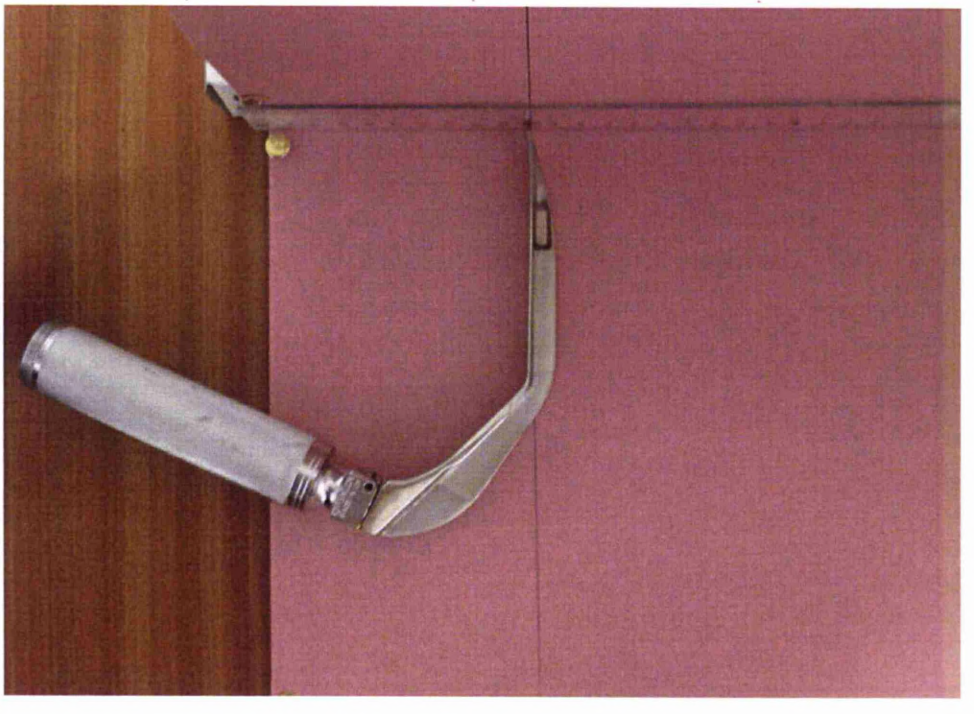

Figure 15 The bench set up for measuring FOV, as viewed from above

Here the Belscope rests on a pink card on the bench with another card rising vertically up from the bench at right angles to the first with measure at its base.

Method

Figure 15 shows view of the bench looking from above. Two pink card papers were aligned at right angles to each other, with one card on the bench and the other at right angles to it. This vertical card had a measuring scale. The laryngoscope blade and handle are parallel to the bench. The distal straight segment of each laryngoscope (Viewmax, both sizes of Truview EVO2 and Belscope) was aligned at right angles to the scale. A Laser light directed through the optical systems produced a sharp image on the scale. A laser projection system ('Laser level 30', Strait-Line Inc., OH, USA) was used to project a narrow laser beam onto each optical device. The laser needed to be precisely lined up with the centre of the optics to maintain a sharp image on the scale.

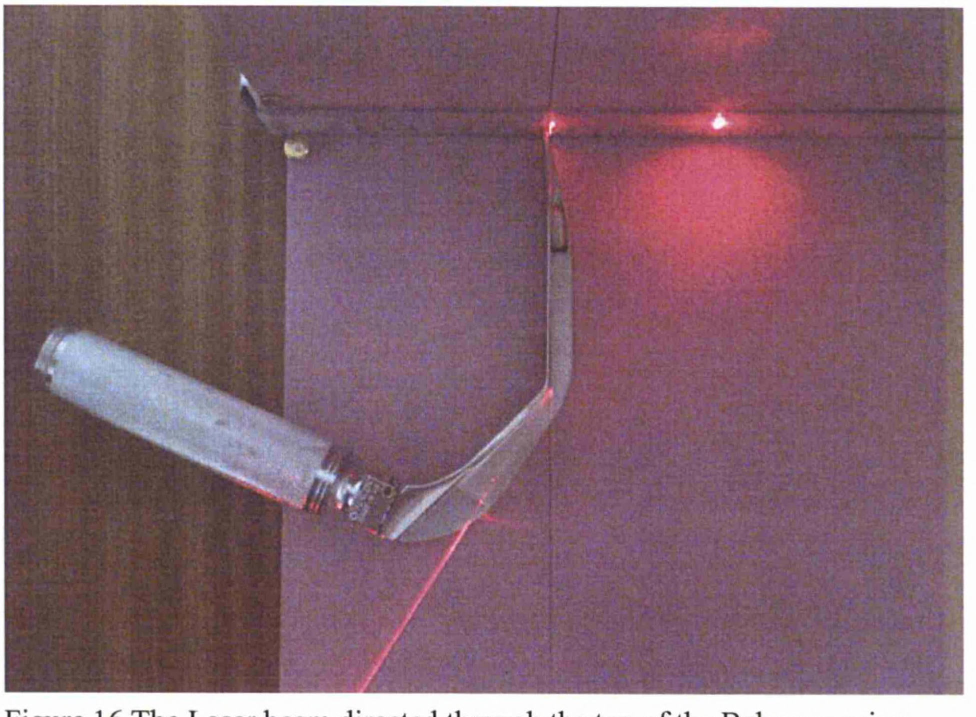

Figure 16 The Laser beam directed through the top of the Belscope prism.

It is seen as the refraction of light toward the tip of the blade (and unrefracted light appearing as a spot above it on the measuring scale)

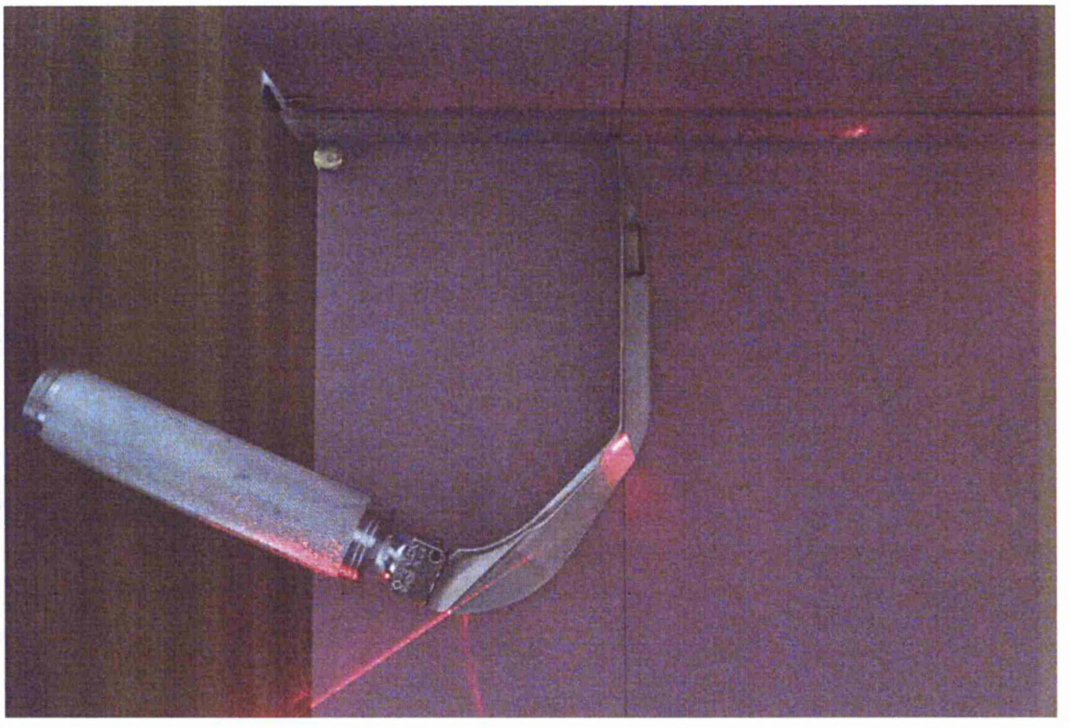

Figure 17 The laser beam directed through the bottom of the Belscope prism.

Maximum upward deflection is seen as a dot on the measuring scale.

Figures 16 and 17 demonstrate the technique for Belscope. In figure 16 there are two light spots along the scale. The laser beam is directed through the upper rear corner of the prism to exit distally and hit the scale. The majority of the beam is directed to get maximum lower deflection along the blade tip. This is the first bright spot that would remain same for all the blades. Figure 17 shows a single bright spot on the scale. This is produced at maximum deflection through the prism and away from the blade. Note that the laser couldn't be directed through the lowermost portion of the prism as the blade handle comes in the way. If it was possible to have a beam parallel to the lower portion of the prism, the maximum deflection away from blade would be further away on the scale. This "corner cut off" occurs due to the way handle/blade was designed (the prism was a later addition to the design).

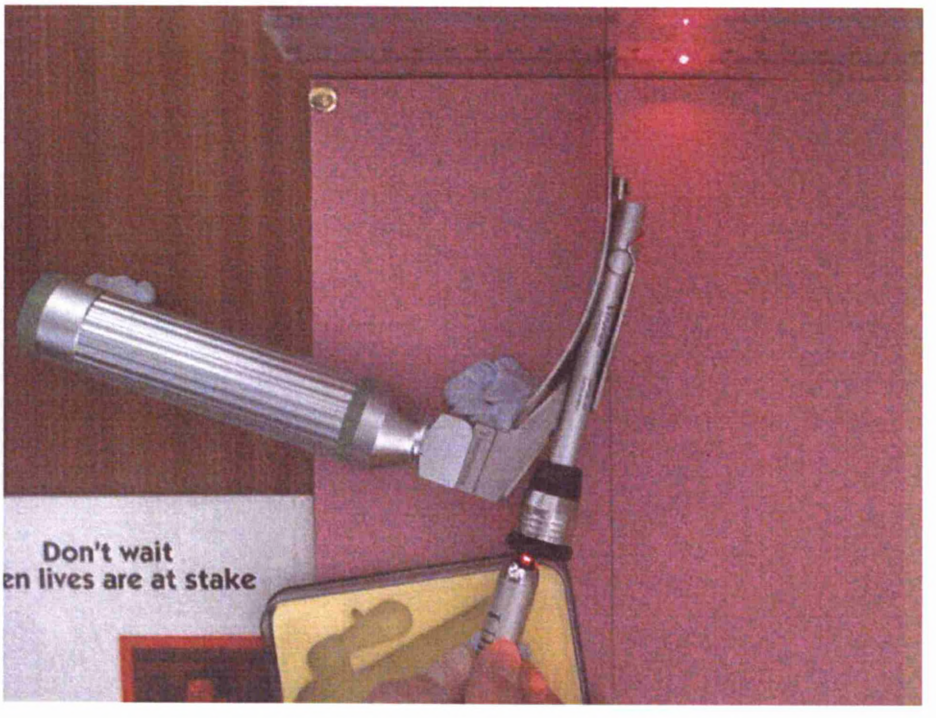

Figure 18 Bench set up for the Viewmax blade.

Laser directed through the viewing tube shows maximum deflection on the scale.

Figure18 shows the experimental set-up for the Viewmax blade. Here the laser beam has to be kept close to the eyepiece. If one moves away from the eyepiece the corner cut off is more pronounced. This emphasizes the fact that the eye has to be kept close to the eyepiece.

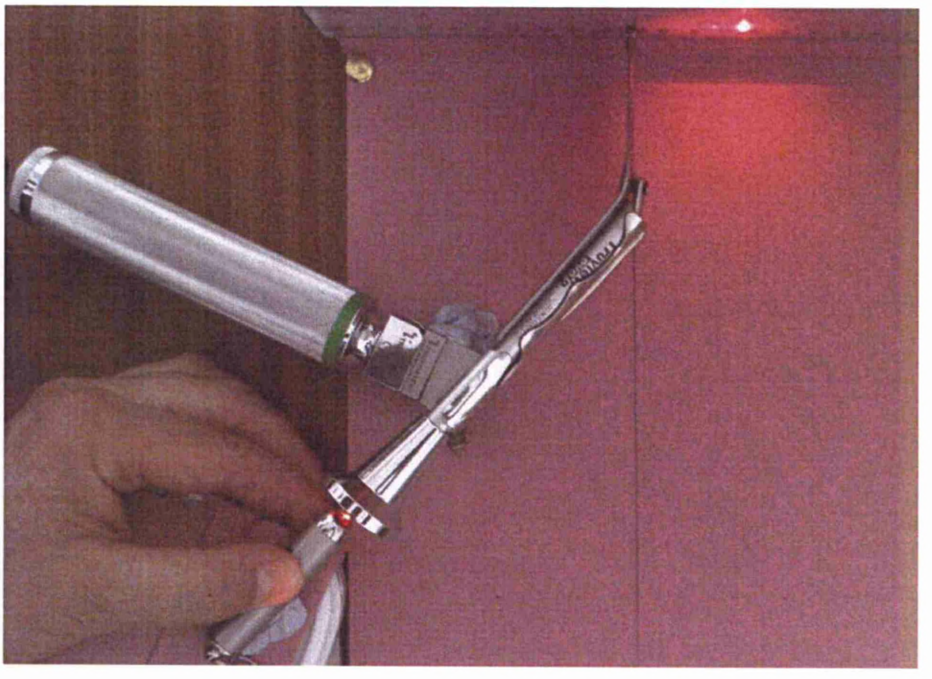

Figure 19 Bench set up for Truview EVO2 blade.

Laser directed through the viewing tube shows maximum deflection on the scale.

Figure 19 shows the set up for Truview EVO2 (large blade). The bright spot on the scale is the maximum deflection of the beam away from the blade.

For each blade, the angle formed by the optical system between maximum upward deflection and maximum downward deflection along the blade (distal straight segment) was measured. This gave the value for the Field of Vision angle.

Results

Blade	DSS (cms)	Blade angulation (deg)	FOV (deg)
Belscope	9.7	45	38
Viewmax	4.7	Curvilinear	22
Truview EVO2 (small)	3.9	45	33
Truview EVO2 (large)	5.5	45	33

Table 1 Field of Vision angle results

Table shows the measured FOV angles, distal straight segment lengths and blade angulations for the respective blades

These results show that Viewmax or Truview EVO2 hasn't shown any improvement in FOV compared with Belscope.

Discussion

Prisms never proved popular in clinical practice. The reasons included difficulty with seeing through them and difficulty manoeuvring the tracheal tube tip into the field of vision. This study showed that while Truview has a striking similarity to the Belscope laryngoscope, both in its construction and working, it has a smaller FOV. On the other hand, the addition of the eyepiece that can be conveniently interfaced with an endoscope camera system does improve visualisation through the prism. However, having the camera attached in this way must interfere with manoeuvring the tracheal tube tip into the field of vision because of the bulk of the eyepiece itself.

2.3 Evaluation of the field of vision for the Airtraq laryngoscope

(This was a poster presentation at the Difficult Airway Society Meeting, Portsmouth, November 2007)

Following on from the previous study, Airtraq was evaluated for its Field of Vision and how a tracheal tube is delivered into it by the tube channel. Airtraq's Distal Straight Segment is 3.8 cm, which was the shortest of the laryngoscopes studied in this thesis. (See Section 2.1). We were interested in whether a short DSS could have implications for both the ease of obtaining an adequate view and for intubation through the lateral channel (since the latter has the net effect of steering the tube in a fixed direction relative to the field).

Method

The laser projection method described in section 2.2 was used to determine the FOV. A 7mm standard tracheal tube was then advanced through the lateral channel to simulate intubation. It was assumed that for an intubating position, (blade tip in vallecula) the vocal cords would be 1cm away from the tip of the blade. The target zone for the tracheal tube was then mapped against the field of vision. Simple manoeuvres, including the use of laryngoscope tilt, and passage of a suitably curved intubating bougie (inside the tracheal tube), were then investigated to determine their effect.

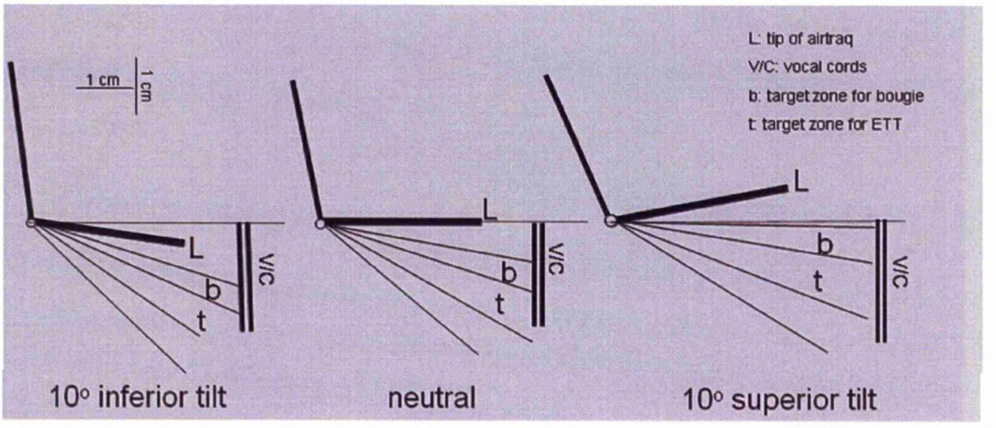

Figure 20 Field of Vision mapping for the Airtraq.

The abbreviations are as indexed in the figure.

Results

The Field of Vision for Airtraq was 41.5 degrees. The target zones for the tracheal tube ($t = 12^{o}$, relative to the Airtraq DSS) and the bougie ($b = 8^{o}$) are shown with different degrees of tilt of the laryngoscope in figure20.

Conclusions

The Field of Vision of 41.5 degrees for Airtraq compares favourably with other indirect viewing laryngoscopes. However, the design of the instrument means that the lateral intubating channel directs the tracheal tube as shown in the diagram (zone 't'). It is possible to intubate above this target zone using a suitably curved bougie (i.e. protruding anteriorly) in advance of the tracheal tube tip (zone 'b'). In addition to this possibility, tilting the airtraq may allow adjustment of the position to get the vocal cord into the appropriate part of the field of vision. However, in the clinical setting, tilting may be limited by the bulk of the equipment as well as rigid bony structures (e.g. mandible). Another obvious alternative would be to raise the Airtraq tip position higher than the laryngeal inlet. In general the advantage of proximity to the laryngeal inlet tends to be offset by the advancing tracheal tube obstructing the view. This problem has been well documented for the Bullard laryngoscope which also has a tube-guiding channel. [43]

2.4 Blade alignment and changes to the FOV projections

This study was presented as a poster at European Society of Anaesthesia meeting, Munich, June 2007.

Blade alignment is the angle between the distal straight segment and the object under consideration i.e. the laryngeal inlet. It is important to know whether this alignment alters the linearity of the object seen in the FOV and whether this might also have implications for tube delivery towards the laryngeal inlet. A bench model was used where blade alignment was altered and the effect on the object image analysed. The blades used in this section were Glidescope, Truview EVO2 and Airtraq.

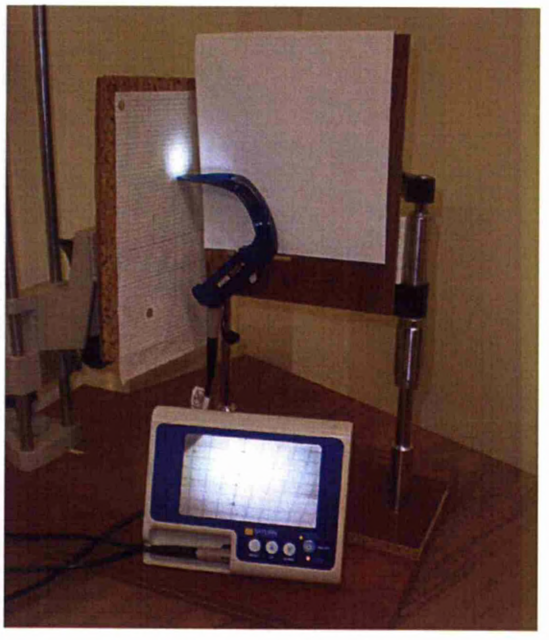

Figure 21 Bench setup showing Glidescope blade tip abutting vertical plane

Angles were measured from the under-surface of the blade to the board.

Method

A 5x5mm graph paper was fastened to a rigid board (figure 21). Blade tips were positioned in contact with the board and the apparatus allowed alterations in the angle between the blade distal straight segments and the board. Each blade was rotated 30 degrees either side of normal (i.e. right angles between the distal straight segment and the board) in 10 degree intervals steps (i.e. 7 measures for each blade). For Airtraq and EVO2, their optical cables were connected to monitor stack systems for image projection and recording to digital outputs. Glidescope comes with its own monitor, which needed to be photographed for subsequent analysis. The images were then processed to count the number of squares visible at each angle and individual square sizes (in both horizontal and vertical dimensions). Based on an observation of linearity for the starting normal position (i.e. squares were projected as squares), a mathematical model was derived to predict the expected cell count and individual square sizes for altered blade alignments (see Appendix A). These projected square sizes were then compared with the model's predicted values.

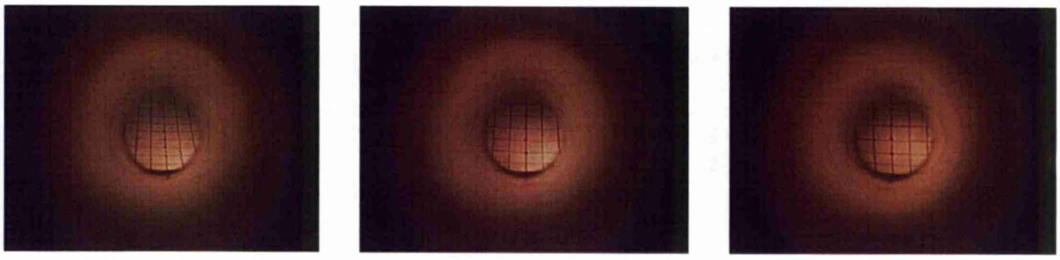

Figure 22 Truview EVO2 screen viewed at blade angulations 60^0,90^0 and 120^0.

Here the screen top represents the contact between the blade tip and the board.

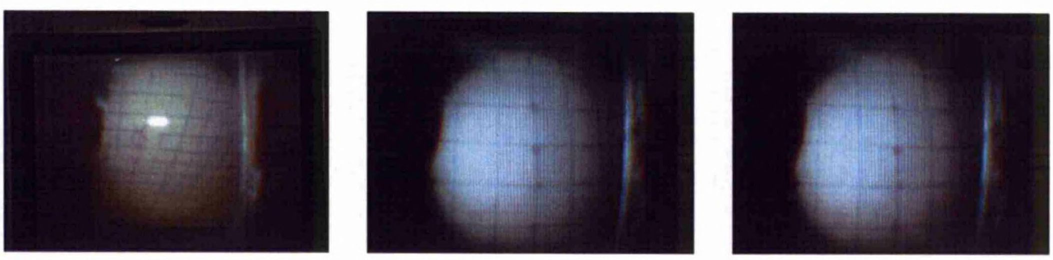

Figure 23 Airtraq screen viewed at blade angulations 60^0, 90^0 and 120^0.

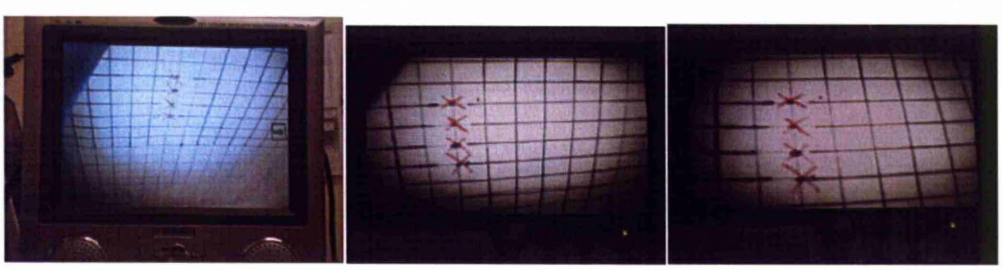

Figure 24 Glidescope screen viewed at blade angulations 60^0, 90^0 and120^0.

Figure 25 Picture of larynx viewed on the Glidescope screen

Blade is angulated at 60^0, 90^0 and 120^0 and as with figures 22 to 24, the blade tip is at the top of the screen.

Results

The mathematical model predicted cell size well for the imaging systems. Screen images were only represented as true squares when the graphical object was at 90 degrees to the distal straight segment. At more acute angles, the upper part of the graph paper was further away from the camera eye, so vertically there were more cells which decreased in size towards the bottom of the image and they became more rhomboid in shape. The opposite was the case when the angles were more obtuse. Any increase in overall amount of the object seen at more acute angles comes at a cost of greater distortion of the image.

Discussion

The analysis appeared to be important in highlighting localised defects in the optical systems and their likely clinical consequences. Ideally the anaesthetist might wish to have a perfect image projection (i.e. squares represented as squares on a screen) with the device at 90 degrees to the object (i.e. the larynx). In our view this is unlikely to be true in most clinical settings and more so in cases of difficulty where there exists a distinct possibility that the image presented to the operator will be distorted. In that case the anaesthetist will not only have the distorted image to deal with, but also equivalent problems in terms of tube delivery into the FOV. This means that at the very least the anaesthetist needs to be aware of whether the larynx image appears relatively wider or narrower at the level of the arytenoids (as seen in figure 25). With Airtraq, these distortions are more likely to be important because of its shorter distal straight segment.

Appendix A- Mathematical Calculation to determine individual square sizes

2.5 Conclusions

The FOV was evaluated for each indirect laryngoscope.FOV for Truview EVO2 was smaller than for both the earlier Belscope prism and the newer Glidescope and Airtraq.

Airtraq had a larger FOV and it also incorporates an intubating channel that lies parallel to optical channel. This channel directs the tube into a specific target zone in the FOV. When the inlet is not within this target zone, Airtraq can be tilted to allow this to occur. However, this may not be always possible in clinical practice due to the bulk of the instrument.

Bench studies showed distortions in the FOV images when the blade tip to the target (laryngeal inlet) alignment was not at right angles. Again this would have implications for tube delivery.

Blade	**DSS (cms)**	**Blade Angulation (degs)**	**FOV (degs)**
Belscope	9.7	45	38
Viewmax	4.7	Curvilinear	22
Truview EVO2 (small)	3.9	45	33
Truview EVO2 (large)	5.5	45	33
Airtraq	3.8	Curvilinear	41.5
Glidescope (GVL)	6.0	60	35.8

Table 2 Summary of all the indirect laryngoscopes FOV evaluations

Section 3 Mac-alike functionality

This section details evaluation of the indirect laryngoscopes relative to their "Mac-alike" functionality or otherwise. "Mac-alike" is a new term that was used for the first time in this thesis to define Macintosh like behaviour of Indirect laryngoscopes. "Mac-alike" functionality describes both good and bad properties of Macintosh (see below). All four devices were tested in an airway simulator, AirSim (Trucorp).

3.1 Mac-alike functionality

Macintosh laryngoscopy has been studied well in the past [44] but such information is not available for indirect laryngoscopes. In 1990 Horton and colleagues proposed reduced oro-pharyngeal space as a "final common pathway" for most cases of difficult Macintosh laryngoscopy [45]. A causative "peardrop effect" was described to explain the "worst-case" situation when the epiglottis appears fixed on the posterior wall of the pharynx. (A "peardrop" is a type of confectionary, which is pear-shaped.) The basis for this hypothesis was radiological imaging of normal volunteers versus patients with a history of difficult laryngoscopy. These subjects underwent conventional direct laryngoscopy in a standardised position with "spray as you go" local anaesthesia. Lateral neck x-ray films taken at the moment of best laryngeal view showed a progressive change from contact with the hyoid in normal subjects to none in the most difficult cases.

In normal laryngoscopy with Macintosh (figure 26), the main limitation is the tongue which needs to be pushed to one side. The 'inevitable residual volume' (dotted line in the diagrams) is that part of the tongue which is not displaced. This IRV has to be accommodated between blade and the mandible or the space immediately below the mandible. Under normal conditions this is accommodated easily. Ideally the blade tip is positioned immediately behind the body of the hyoid so that, from a lateral perspective, the greater horns of the hyoid get lifted clear of the posterior pharyngeal wall.

However when the oro-pharyngeal space overall is reduced (figure 27), the first thing that happens is that the tongue gets pushed down the oro-pharynx by virtue of the Macintosh blade being inserted into the mouth. Contact with the hyoid is less likely because it is harder to get around the tongue mass. In addition, because contact with the hyoid body is less likely, the depth of blade insertion is much less precise. (X-ray laryngoscopies showed that it is unusual for it to be at the level of the hyoid.) Furthermore, as the hyoid is not pulled forward, the epiglottis remains in contact with the posterior pharyngeal wall. When attempts are made to pull the blade forward, the tongue starts to be wedged even further down into pharynx because of the squeezing against the inner surface of mandible. The same processes that limit laryngeal descent during swallowing halt downward descent of the tongue. The force now disseminates radially to limit forward movement of the blade. When this happens tongue assumes a pear shape due to the "neck" formed at the inner surface of mandible. As a result the epiglottis appears fixed to the posterior pharyngeal wall. This is termed "the peardrop effect".

A "partial peardrop effect" is when some movement of the epiglottis off the posterior pharyngeal wall is possible but not enough to give a view of the underlying laryngeal structures.

This mechanism for Macintosh laryngoscopy suggests the following functional elements:

- The need for tongue to be displaced
- The need for adequate mandibular space for this displacement
- The need for sufficient force for tongue displacement
- The need for a clear direct line of view down to the exposed larynx

Indirect laryngoscopes differ in both the lengths of their distal straight segments and their blade angulations (refer to section 2.2). Because of this it was hypothesized that individual tongue displacement profiles and the force needed for effective use for each would vary compared with Macintosh. To demonstrate this Truview EVO2, Airtraq and Glidescope were compared with Macintosh in an AirSim manikin by creating difficult laryngoscopy conditions by way of progressive space reduction. A proxy for the force used at laryngoscopy was the pressure applied to the tongue and this was measured by attaching a clinical pressure transducer to the tongue valve of the AirSim.

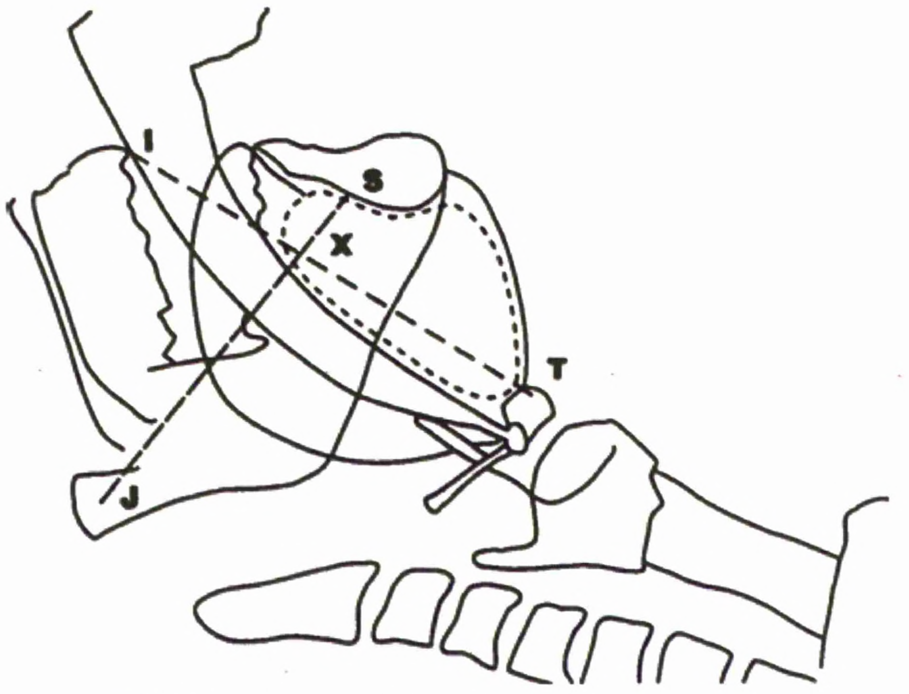

Figure 26 Line diagram of normal x-ray laryngoscopy

The reference points are: J= radiological midpoint between the two condyles; I= tip of maxillary incisors; S= midpoint on the inner surface of mandibular symphysis; T= most antero-inferior position of the airway behind the thyroid cartilage and above the vocal cords and X is where lines IT and JS intersect. The diagram shows expected position of the laryngoscope blade relative to the tongue. The blade is completely round the tongue reaching to just behind the body of hyoid. The main bulk of the tongue is pushed forward between the mandible and the hyoid ('Inevitable residual volume', small dashed line).

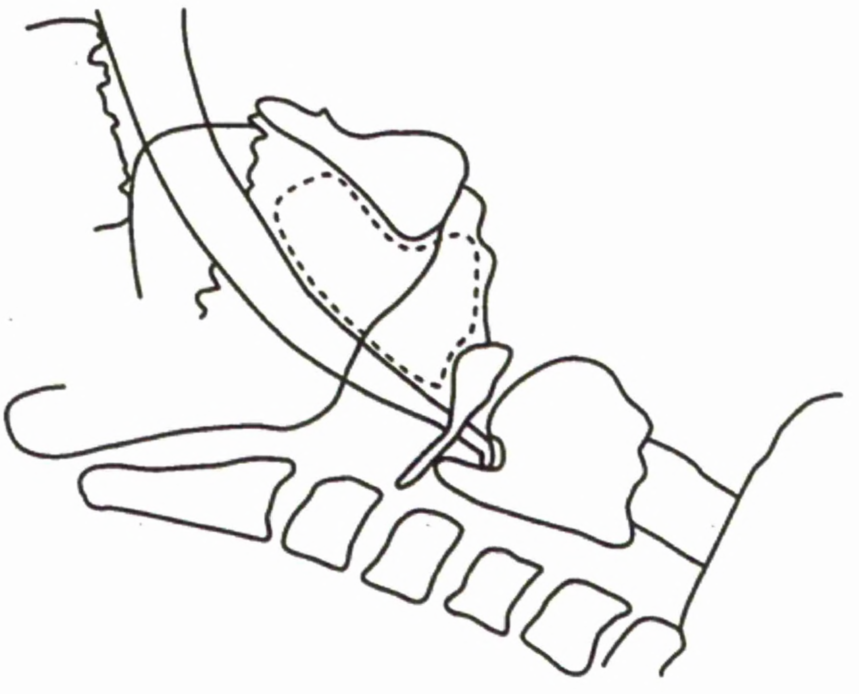

Figure 27 Disposition of tongue under difficult laryngoscopy conditions

The laryngoscope blade tip is pressing against the epiglottis, which is folded down against the posterior pharyngeal wall. The blade tip is well back from the hyoid body. By comparison with figure 26, the tongue appears relatively large and the area involved in the peardrop effect is shown by a dotted line.

3.2 The AirSim

The AirSim (Trucorp Ltd. Belfast, N Ireland) is a commercially available airway training manikin. It has been used to evaluate various laryngoscopes and is well validated for this purpose. [46-48] The AirSim was chosen because it has several important features. First of all it is constructed from a polymer moulded from a master, which was created from data collected from a human CT scan (figure 28).Its integrated, one piece and seamless construction, and the materials used, produce a realistic tactile feedback with airway manipulations. [49]The internal view on laryngoscopy is as seen in figure 29.

The AirSim trainer comprises two distinct parts. [50]

The anatomical component- This includes one-piece, CT data derived complete adult airway. It includes breakaway incisors along with laryngo-phayngeal structures. The tongue can be inflated to various sizes by attaching an air/water filled syringe to the inflatable valve thus creating a variable oro-pharyngeal space.

The mechanical component- It has a robust mounting fixed neck plinth, a ball socket arrangement for head on neck movements and a jaw attached via bilateral spring loaded mechanisms equivalent to temporo-mandibular joint movements (see figure 28). The neck is fixed at 30 degrees relative to horizontal, while the head can be rotated from 50 degrees of extension to 30 degrees of flexion. Head positions can be easily measured with suitable angle-finder. The jaw arrangement allows an obvious jaw thrust and the larynx not only moves up and down with head and neck movements but can also be lifted off the cervical spine.

Figure 28 The AirSim manikin is seen in a side profile.

Metal props are kept below the occiput to vary and stabilise the head position

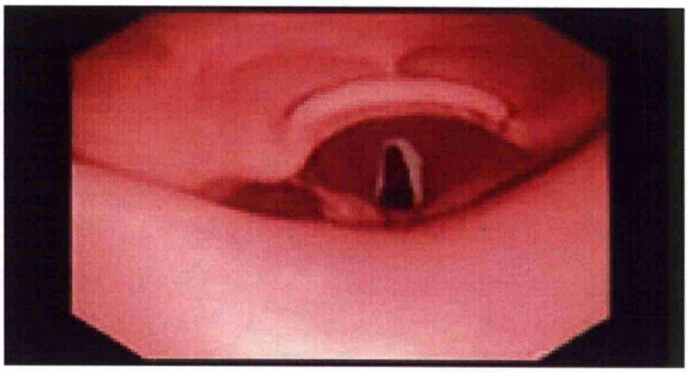

Figure 29 Internal view of the AirSim manikin to show the larynx

Methods

The AirSim tongue has a resting volume (approximately 30mls) as demonstrated when the valve is open to the atmosphere. The tongue volumes from -20 to +100mls (in 20ml increments) relative to this resting volume were studied. The angle for the neck plinth is fixed at 30 degrees relative to horizontal while the head position is adjustable via its ball and socket joint. Almost the entire range of head positioning available, i.e. from 30 degrees flexion to 50 degrees extension, were studied in 10 degrees increments. (Angles were measured relative to the horizontal plane using "Angle finder"). [51] For all head positions and tongue inflations three laryngoscopy grades were described: 1. Normal- some view of the laryngeal structures, 2. Partial-a partial peardrop or 3. Full- a complete peardrop effect. Preliminary trials had shown the ball-and-socket head joint to be unreliable under the stress of normal laryngoscopy so an adjustable prop under the manikin occiput was used to ensure fixed head positions at each setting. All the laryngoscopies were performed by two anaesthetists, each working on separate AirSims. Each anaesthetist performed laryngoscopies initially at progressively increased tongue volumes and neck flexion angles and then in the reverse order. (Their results were combined and averaged.)

The pressure exerted at laryngoscopy was measured with a clinical transducer attached to the tongue valve for each laryngoscopy attempt (figure 30)
The AirSim manikins had the "breakaway teeth" options and these were deliberately protected by the laryngoscopists as part of the laryngoscopy protocol (i.e. no contact with the upper incisors was allowed). A further consideration was the tendency for laryngeal structures to be pulled forward during laryngoscopy under certain conditions. This was usually obvious to the person not performing the laryngoscopy and simple backwards pressure (rather than a full BURP manoeuvre) was encouraged to counter this effect.

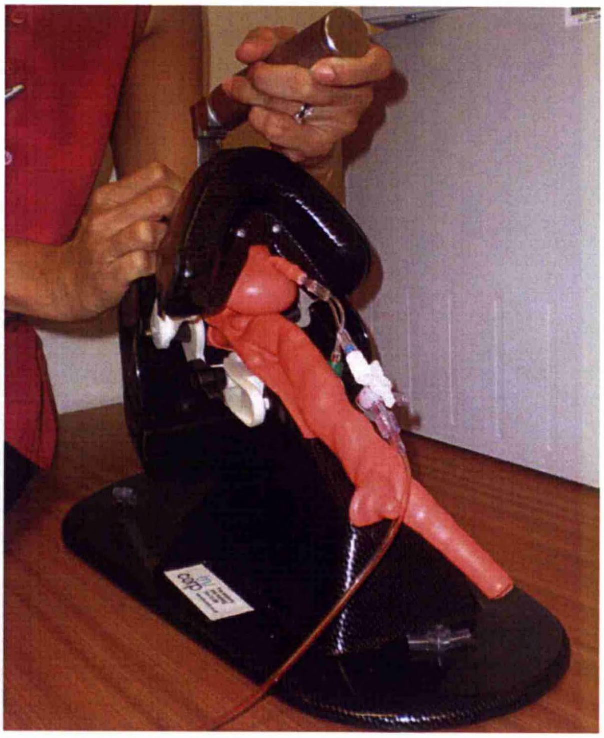

Figure 30 AirSim manikin during laryngoscopy

The tongue is seen bulging below the mandible as described in the text. Here the tongue was inflated to +60ml and the laryngoscopic view was a partial peardrop.

Results

The results will be described in two parts, the changes in laryngeal view and changes in the pressures measured.

Figure 31 shows variation of the view at each laryngoscopy with differing tongue volumes and head flexion angles. Normal larygoscopic views were obtained in all of them with small tongue volumes and good head extension. A partial peardrop was also evident as a regular diagonal distribution band from the top left to bottom right of these graphs.

With Macintosh laryngoscopy, even at resting tongue volume, with increasing head flexion the view started to disappear and be replaced by a partial peardrop effect. As the tongue volume was increased the worsening of view with increased head flexion appeared progressively earlier. At 60 ml volume and above no normal view was possible.

With Glidescope there was a similar gradation of peardrop effect but there would appear to be a lessening for the neck flexion needed for it to start occurring. From the tongue volume point of view at +60ml it appears to out-perform Macintosh. (A normal laryngoscopic view is still possible in contrast with Macintosh.) On the other hand a new and important constraint became apparent with Glidescope i.e. it is not possible to insert it at all under certain tongue volume and flexions. This was described as 'no view', as shown by the clear boxes in figure 31.

With Truview there was a broadly similar pattern to both Macintosh and Glidescope with some normal views at +60ml similar to Glidescope. At resting tongue volume, any partial peardrop occurred later than with Macintosh. There was no restriction with blade insertion.

Airtraq was unique in giving some normal laryngoscopic views at all tongue volumes and the partial peardrop always occurred at greater head flexion. At +80ml tongue volume and marked head flexion, its bulk did not permit laryngoscope insertion, though even this limitation was better than Glidescope.

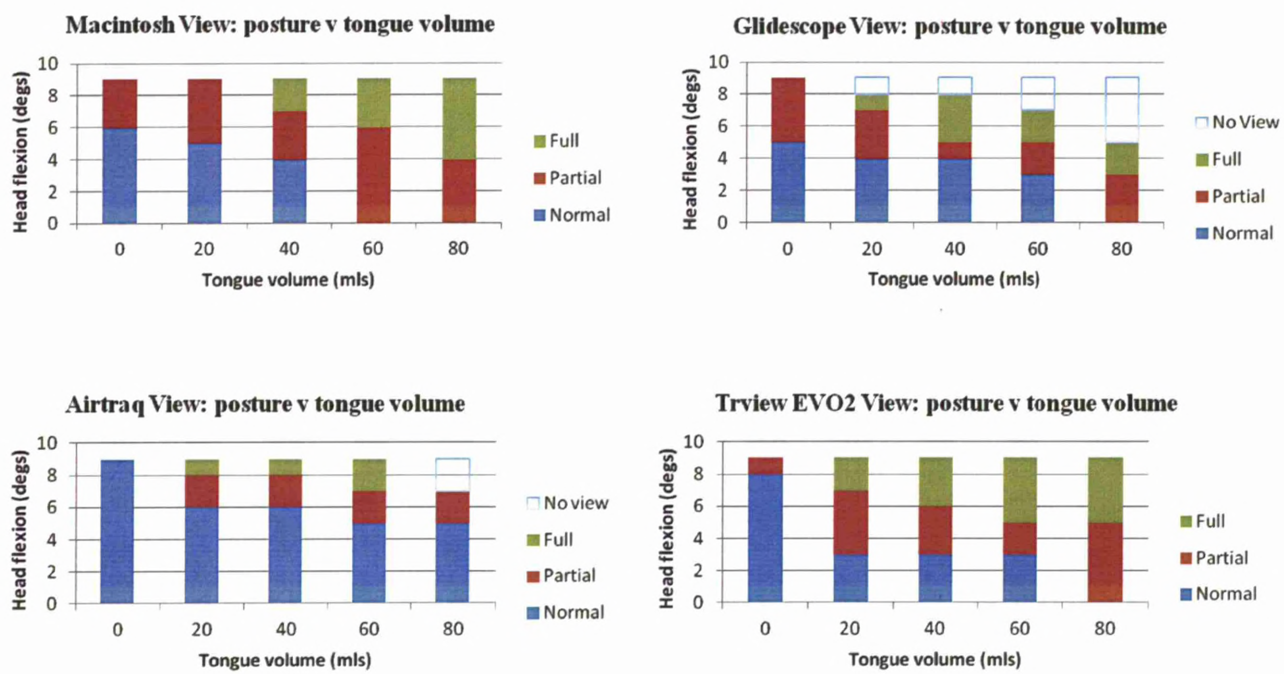

Figure 31 Boxplots of views for Macintosh and IDL laryngoscopes with changes in head flexion and tongue volumes.

Tongue volumes (mls) are on the x-axis and the y-axis represents both head flexion in degrees and running counts of the views: normal (blue), partial peardrop (red), full peardrop (green) or no view possible (clear outline). The y-axis is labelled for total counts but equally represents increasing head flexion from -50 to 30 degs (in 10 deg steps) so that -50degs is equivalent to '1' ; -30 degs is equivalent to '3'; 0degs is equivalent to '6' and +30degs is equivalent to '9'.

Figure 32 shows the pressure changes within tongue measured by the clinical transducer at laryngoscopy with Macintosh and then the IDLs. Overall the pressures tended to increase with decreasing oro-pharyngeal space (i.e. increasing tongue volume and increasing head flexion). Only at resting tongue volume and for Glidescope and to a lesser extent Truview was this not always the case. It also appeared to be the case that pressures overall quickly tended towards a maximum value of around 160mmHg. With this manikin, higher volumes tended to be associated with tongue "blowouts" (i.e. blows out to one side as seen in figure 30), which was obviously a limitation of the model. Truview was like Macintosh and Glidescope in terms of the pressure profiles whereas Airtraq had lower pressures, especially so at the resting tongue volume.

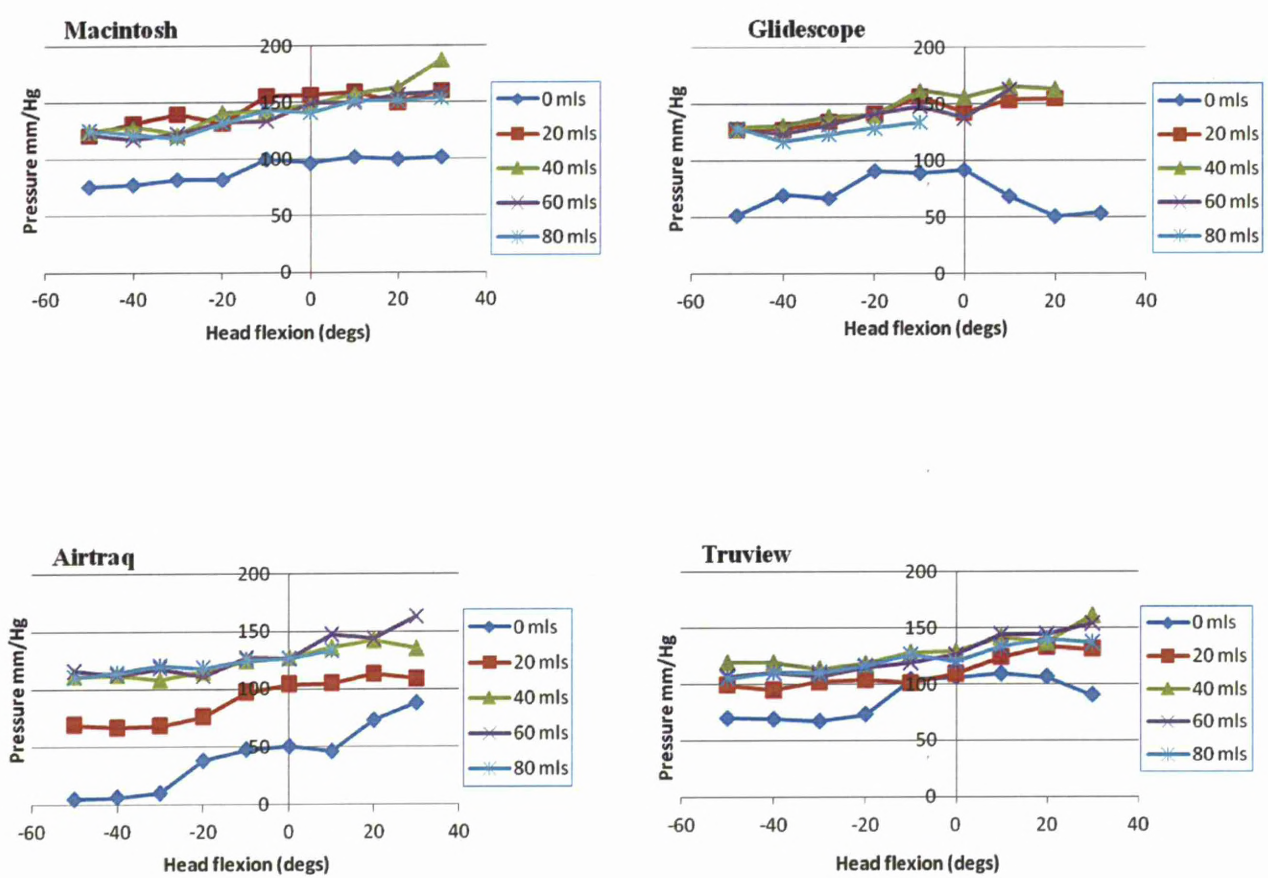

Figure 32 Pressure changes within tongue on laryngoscopy with Macintosh, Glidescope, Truview and Airtraq at various tongue volumes and head flexion angles

Discussion

Use of a manikin to demonstrate complicated mechanisms in human physiology can be criticized as having inevitable limitations. Difficulty in characterising the jaw/mandible settings is an obvious problem here. In addition the tongue can hardly be expected to behave as a homogenous tissue when it is known that tongue compression needs to take into account the blood supply (which is drained when compression starts) before its complex muscle structure can then be considered. [52]The AirSim mandible also has a prominent internal ridge to which the internal airway parts are anchored. Most of these considerations however become less important when different blades are assessed relative to one another in the settings.

This study clearly showed that Airtraq has an impressively different tongue displacement profile from the other blades because it tends to give a better view and at lesser cost in terms of pressure applied to the tongue. This must mean that its IRV is effectively smaller resulting in less tongue needing to be accommodated in the space immediately below the mandible. Why this should be the case only became clear with work later in this thesis (Section 5). Importantly at this point, this result supports earlier evidence that the peardrop effect is not inevitable, that it is particularly associated with use of the Macintosh blade and that it can be avoided or even "reversed" (see later).[53]

As far as Macintosh itself is concerned, both increased head flexion and greater tongue size would be expected to decrease the relative oro-pharyngeal space and in that sense this experiment proved to be an elegant support for the peardrop hypothesis. The tendency for a complete peardrop to occur regularly at maximum head flexion also reinforces the important notion that downward movement of the tongue generally initiates the phenomenon. The relevance is that this makes contact with the hyoid even less likely than would otherwise be the case. This first physical demonstration of the peardrop effect is noteworthy because of its value in helping anaesthetists to see and understand how the mechanism occurs.

Although no BURP manoeuvres [54] were allowed as part of the study protocol it is easy to understand why use of this manoeuvre would be unlikely to overcome a complete peardrop effect. At the same time, there is clearly potential for improvement with the partial peardrop (where the epiglottis is not fixed against the posterior wall). In any case the main clinical message is that excessive laryngoscopy force tends to be counterproductive, especially in the complete peardrop situation. (The excessive laryngoscope forces considered here would tend to counter those needed to produce an effective BURP manoeuvre anyway.)

The original description of the peardrop effect was that it should be considered as a "final common pathway" for most causes of difficult intubation. The obvious example usually cited for demonstration purposes is a "progressively receding jaw."[45]It transpires that most causes of difficulty result in a reduction in the oro-pharyngeal space into which the tongue volume (IRV) can be displaced. This would include macroglossia (and any other cause of relative increase in tongue size or decrease in compliance), fixed head flexion deformity, reduced jaw translation etc. [7]

A recent demonstration of the peardrop effect by Nishikawa et al. was in a prospective investigation of the patients with unexpected difficult airway using X-ray laryngoscopy. He introduced a novel concept termed a "reverse peardrop effect", which was the basis for a new laryngoscope blade design. [(53)] This curved blade was designed to "exert more effective pressure in the vallecula area, elevate the epiglottis and change direction of the forces on the tongue to prevent postero-inferior displacement of the compressed tongue in the submandibular space during laryngoscopy".

Nishikawa et al. also considered that, although the unexpected difficult airway may be caused by the multifactorial minor disorders in the upper airway (i.e. there may be no obvious anatomical features indicating a difficult airway), the peardrop phenomenon is the end point change in the dynamic anatomy during direct laryngoscopy (i.e. laryngoscopy-induced airway obstruction). This was the basis for reversing the peardrop phenomenon as the key to solving this problem. Equally the simulation used for the present study is the first physical model demonstrating the peardrop effect and it should prove to be important for evaluation of any device that claims to have advantages over the Macintosh blade.

The peardrop phenomenon can also explain how multiple laryngoscopies in difficult cases can lead to a congested oedematous tongue that is unlikely to return easily back to its starting position on withdrawal of the rigid blade. Repeated forceful laryngoscopy not only starts the process off, but accelerates its progress leading to progressively worsening airway obstruction. This is probably the first reasonable explanation as to why "can't ventilate, can't intubate" can develop as a result of difficult laryngoscopy when this was not the case immediately before any laryngoscopy attempt started.

Another important consequence of reduced oro-pharyngeal space as the main cause of difficult laryngoscopy relates to when a laryngeal mask airway is being considered to manage these situations. The obvious rationale would be to use a smaller size to what might otherwise be considered. Local practice at University Aintree for some years now is to start with a size 2.5 in any adult with any compromised airway and this has regularly produced an adequate seal for ventilation. This is in sharp contrast to the manufacturer's and other investigators' recommendations to use as large as size as possible. [55][56, 57]

Demonstrating the peardrop effect by simulation also offers opportunities for teaching trainee anaesthetists how to recognize this uncommon problem and clearly shows the importance of increased pressure with the laryngoscope only making matters worse (i.e. that excessive pressure on the tongue is entirely counterproductive).

3.3 Comparison of Blade-tracheal alignment angle

With Macintosh laryngoscopy intubation is usually intuitive once an overall view of the larynx is obtained; largely because there are no issues in terms of blade-alignment (i.e. blade-alignment remains 3-dimensional even when the view is limited). Little is known about whether blade-tracheal alignment is an issue for indirect optical laryngoscopes. This may be important because, although the tracheal tube is initially presented into a 2-dimensional field of view (the IDL screen), aligning the tube tip to the laryngeal inlet remains a 3-dimensional problem. The changes to FOV projection seen in section 2.4 suggest that blade-tracheal alignment has the potential to be important. Glidescope, Truview EVO2 and Airtraq were compared in terms of alignment with the tracheal axis versus the Macintosh using the AirSim manikin.

Method

Laryngoscopies were performed using Macintosh and each of the indirect laryngoscopes in the AirSim manikin using varied head positions (figure 33). Lateral photographs were taken of each laryngoscopy attempt when the maximal view was obtained. All the photographs were taken at the same fixed distance from the AirSim midline. Equivalent blade shape photographs (taken at the same fixed distance) and a fixed anterior airway line were then superimposed on these photographs to locate the tip of the blade in relation to the laryngeal inlet (figure 34). This required the use of a software drawing package (CorelDRAW™) and Bezier curve techniques as described in detail in Appendix B. The angle between the distal straight segment of the blade, or its tangential equivalent for Macintosh, and the tracheal axis (the "blade-tracheal angle") was then measured (figure 35).

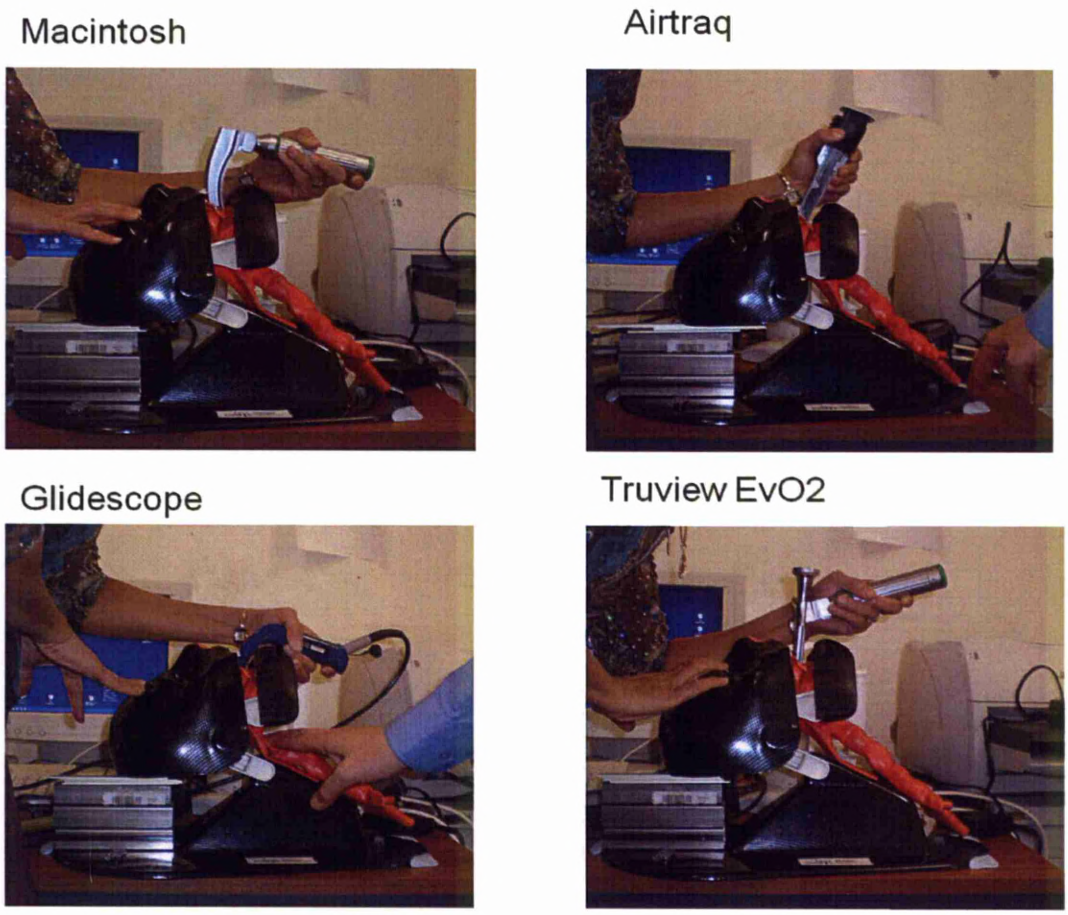

Figure 33 Lateral photograph for each blade using AirSim manikin

Glidescope insert (only) shows the larynx held down to maximise laryngeal view.

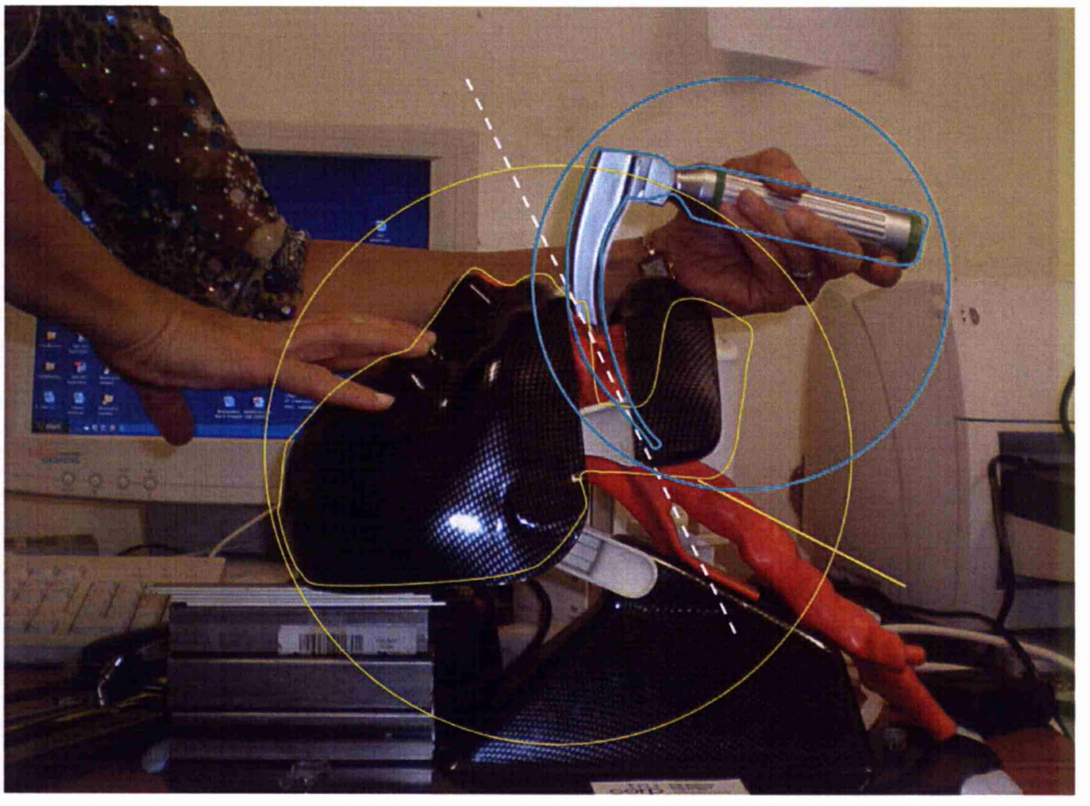

Figure 34 Laryngoscopy with Macintosh and head extension to 30 degs.

Here the yellow outline is the position of the head, jaw and anterior airway line prior to laryngoscopy and the dotted line indicates the tangential view with Macintosh.

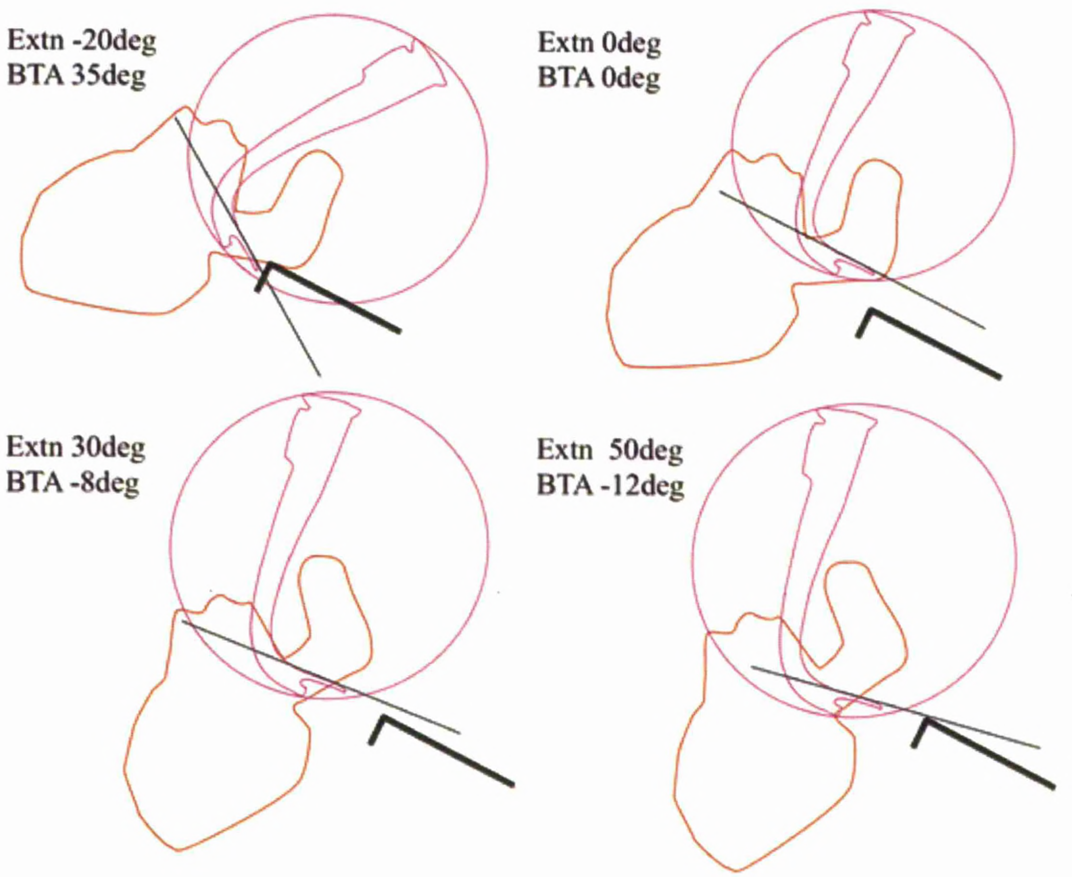

Figure 35 Overlay analysis of Airtraq laryngoscopy at different head positions

Here, instead of a single line, the trachea is represented as an 'L' shape in order to give idea of depth of the inlet. At -20deg and zero deg extension blade-tracheal angles were 35 and 0deg respectively. With increasing head extension the blade- tracheal angles became negative (8 and 12 respectively) and this was the only blade to show this effect.

Results

In moderate extension all the indirect optical laryngoscopes were closely aligned with the tracheal axis (figure 37). Glidescope and Truview had similar blade-tracheal alignments for all the head positions. Airtraq was more closely aligned to the tracheal axis at each position and was the only device that was at times below the tracheal axis.

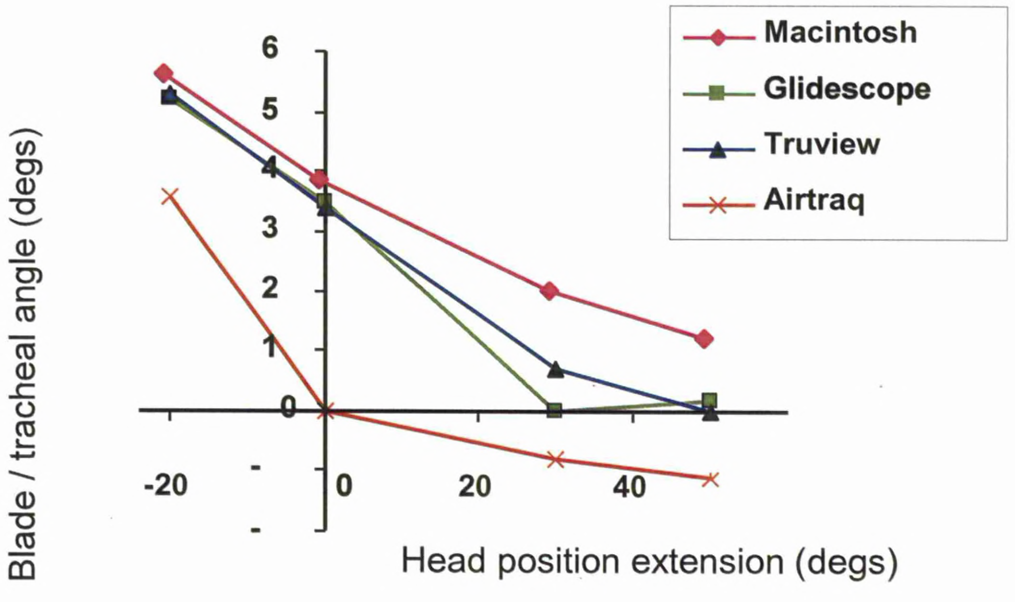

Figure 36 Blade-tracheal angle for each blade at various head extensions

Discussion

In general for, each blade, the blade -tracheal angle increased with decreased head extension. This would be compatible with reduced space into which the tongue can be displaced. It would also imply that Airtraq was less influenced by this than Macintosh or the other indirect laryngoscopes. The negative values seen for Airtraq may be important in causing difficulty with tube advancement because of the various angles that the tracheal tube can impinge on the laryngeal inlet. Lifting the Airtraq up has been suggested as one way of dealing with this difficulty ("back and up manoeuvre") [41] Study of blade-tracheal angles explains why this manoeuvre helps with adjusting the position of the Airtraq tip to deal with this problem.

In overall summary, it is now clear that the view obtained with the indirect laryngoscopes will be largely influenced by the following:

1. Blade-alignment may influence image distortion in respect of the FOV projection. By definition blade-alignment requires the blade tip to always be in contact with the object (graph paper). When the blade-alignment is other than 90 degrees the lower part of the FOV projection will have progressively decreased graph cell size horizontally and vertically (i.e. more cells when <90 degs) or progressively increased graph cell size (i.e. fewer cells when > 90degs).
2. Blade-tracheal angle is similar to blade alignment but does not assume contact between the object being viewed and the blade tip.
3. Blade tip to object distance is important because even assuming a short distance from the laryngeal inlet was enough to suggest earlier that the inlet may not even be in the FOV projection with Airtraq for various blade tracheal angles.
4. Blade tip position relative to object may be important because instead of just considering tilting of the indirect laryngoscope blade, the tip may be moved in other directions, especially vertically. In the case of Airtraq a specific clinical maneuver has been recognized as above to get the object into the FOV projection.

3.4 Conclusions

Based on the previous understanding of the mechanism underlying Macintosh direct larygoscopy it was possible to illustrate properties of indirect laryngoscopy using the AirSim manikin.

The AirSim manikin demonstrated that increasing tongue volume, decreasing space (by neck flexion) or both, made Macintosh laryngoscopy more difficult and that the Peardrop effect was seen with all the blades studied. Glidescope was similar to Macintosh with some improvement at higher tongue volumes though access became a problem at this setting. Truview was also similar to Macintosh, but more readily associated with a Peardrop effect. Airtraq was generally better than Macintosh with decreased tendency to show Peardrop effect and only occasionally causing a problem with access.

For Macintosh the degree of difficulty was associated with more force needing to be applied and this was also true for Glidescope and Truview. Airtraq on the other hand had better force profile.

The possibility of negative blade-tracheal angles with Airtraq may be important in causing difficulty with tube advancement. This finding explains why 'Back and up manoeuvre' has been suggested to deal with this problem. [41]

Section 4 Validation of a model of graded difficulty in Laerdal Sim Man

This section describes evaluation of Indirect laryngoscopes under simulation with Laerdal Sim Man. The simulation was for a progressive reduction in mandibular space. Two native Sim Man settings were used- Normal Airway (Easy setting) and Tongue oedema (Difficult setting) with a novel intermediate level of difficulty created by addition of a removal rigid insert (Intermediate setting). This novel idea was the author's own creation. Twenty anaesthetists performed laryngoscopies with Macintosh, Airtraq, Glidescope and Truview EVO2 in these three settings. To explain the results obtained a novel technique of Overlay drawings is presented.
The overlay technique demonstrates the blade tip positions with respect to the laryngeal inlet and thereby helps understand the laryngoscopic view obtained.
The study also introduces a novel index DELI (Difference Ease of Laryngoscopy and Intubation) to quantify difficulty encountered with indirect laryngoscopes in terms of ease of effecting intubation relative to the view obtained. This peculiar problem with indirect laryngoscopy has been observed in various studies. However this study is the first attempt to quantify this problem and should allow improved designs for new indirect laryngoscopes.

4.1 Validation of a model of graded difficulty in Laerdal Sim Man: functional comparisons between Macintosh, Truview EVO2, Glidescope GVL and Airtraq

(A paper with the above title was published in the European Journal of Anaesthesiology [58] and is reproduced below. References for this publication, are presented at the end of the section 4.1.In addition part presentations of the work in development were presented to the Anaesthetic Research Society meeting, Edinburgh, May 2009 and published as: Br J Anaesth 2009;103 (2): 317–318P and Br J Anaesth 2009; 103(2): 318P.)

Abstract

Background and Objective: A randomised, cross-over study was designed to validate a new model of graded difficulty (based on mandibular space reduction) in the Laerdal 'SimMan' mannequin and to suggest functional comparisons between Macintosh. Glidescope Video Laryngoscope, Truview EVO2 and Airtraq.

Methods: Twenty anaesthetists attempted intubation with all four laryngoscopes in three settings: easy, intermediate (based on a custom-made removable prosthetic insert) and difficult ('tongue oedema', a manikin feature). Laryngoscopic view and time to intubate were the primary outcome measures. Other measures were successful intubation, ease of laryngoscopy [visual analogue scale (VAS)] and intubation (VAS), tongue compression score and number of attempts.

Results: Between settings comparisons demonstrated that Macintosh, Glidescope and Airtraq had worsening scores from easy to intermediate with lesser changes for Truview. However, with the intermediate to difficult comparison, Airtraq was the only blade with no worsening of scores. Within-blade comparisons showed that

Macintosh was superior over all in both the easy and intermediate settings, whereas Airtraq was the most successful blade in the difficult setting.

Conclusion: Our study suggests that Glidescope and, to some extent Truview, are functionally similar to Macintosh and suffer from similar limitations in the difficult setting. On the contrary, Airtraq was functionally unique in providing good laryngeal exposure in the difficult setting and without excessive tongue compression.

Introduction

An increasing number of new indirect laryngoscopes have become available as a result of improved optical technologies. A quantitative review and meta-analysis of the performance of these devices concluded that "there is very limited and inadequate comparative data between devices and compared to the standard Macintosh laryngoscope. A new approach to this area of research is needed". [1] In addition to optical changes, many of the new devices appear different in shape from the Macintosh blade, which implies that they may also be functionally different. One of the main limitations of Macintosh laryngoscopy is failure to provide an adequate view when the mandibular space available for tongue displacement is reduced. [2-7] Current manikins are designed to deal with this feature of Macintosh laryngoscopy in that they have a compressible and displaceable tongue. To understand whether the new blades perform differently we considered that a graded system of relative space reduction (easy, intermediate, and difficult) would be most likely to demonstrate any functional differences. To this end we decided to use the "easy" (normal tongue/ normal space) and "tongue oedema" (large tongue / normal space) standard settings for the Laerdal manikin. For the "intermediate setting" we designed a purpose built "tongue restrictor" (normal tongue/ restricted space) based on a non-deformable, easily removed and inserted prosthesis that was positioned inside the mandible.

We decided to undertake a study with two objectives - to validate our model of graded difficulty and suggest functional comparisons between devices. Indirect laryngoscopes were chosen on the basis of different shapes relative to Macintosh. Glidescope Video Laryngoscope GVL® has a 60 degree angulation in the blade, Truview EVO2 ™ , a 35 degree angulation, and Airtraq® a gentle distal curve.

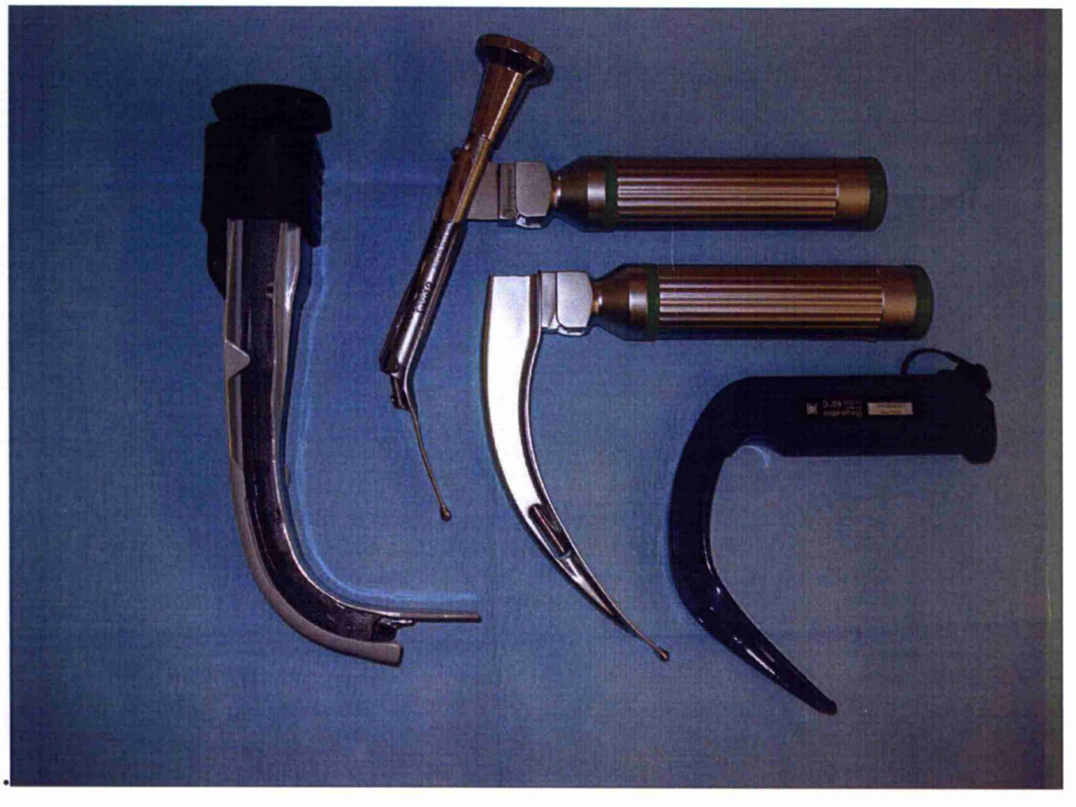

Figure 37 Laryngoscopes evaluated in the study

The instruments (left to right) are: Airtraq®, Truview EVO2™, Macintosh (size 4) and Glidescope® (GVL size 4)

Methods

Following Local Research Ethics Committee approval and written informed consent twenty anaesthetists consented to participate in this study. Power analysis for the number of participants required was derived from the results of our previous similar study.[8] Using time to tracheal intubation, we calculated that 20 subjects would be needed for 90% power to find a 15 sec difference in intubation time for the difficult (tongue oedema) setting and a 5 sec difference in the easy (normal) setting. All the participants were briefed about the study. The instruments we studied were: Truview EVO2™ (Truphatek Int. Ltd; Netanya, Israel), Glidescope (GVL® size 4- Verathon Medical; Buckinghamshire UK) and Airtraq® (regular size 3- Prodol Meditec S.A; Vizcaya, Spain), with a standard size 4 Macintosh blade (Optima, Timesco Limited; London, UK). Apart from the Macintosh blade none of the anaesthetists participating in this study had any prior experience with any of these laryngoscopes. As an introduction to these devices, all the anaesthetists taking part were given an explanation as to the recommended use of the laryngoscopes and each was demonstrated in the normal setting with SimMan. They were then given 30 minutes to practise intubations using the manikin. Intubations with Glidescope were performed using the GlideRite rigid stylet specifically designed by the manufacturer (angle of stylet complements the angle within the Glidescope blade) and instructions for its use were followed as per the manufacturer recommendations. For intubations with Truview, the Optishape stylet recommended by manufacturer was used. A Frova single-use introducer was used for intubations with the Macintosh laryngoscope. For Airtraq no introducer was used. Once they felt suitably familiar with all the instruments, anaesthetists went on to perform the study protocol.

The simulator used was a Laerdal® SimMan. Three settings were used- Easy (resting manikin setting), Difficult setting (Tongue oedema setting) and Intermediate setting (Insert setting). The Intermediate setting was designed to restrict the tongue compression and fashioned from an elastomer silicone knead able material (Finopaste; Kissengen, Germany). The size and shape for this prosthesis was determined in a preliminary study using the Macintosh blade. The size used was chosen for the view obtained and time for laryngoscopy so that each parameter was approximately midway between the Easy and Difficult settings with the Macintosh blade. The suitability of the material was confirmed by its easy insertion, removal and ability to withstand repeated laryngoscopy.

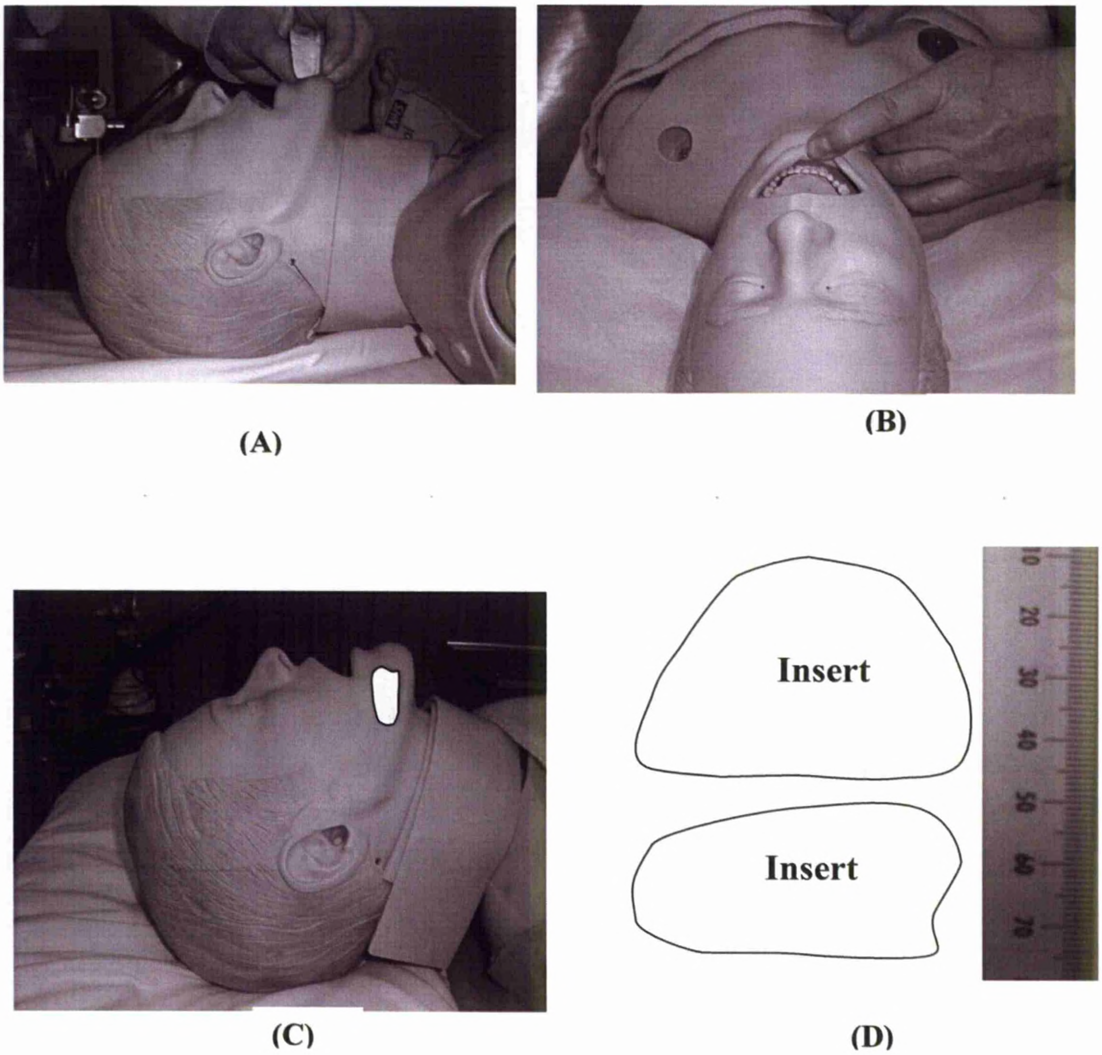

Figure 38 Custom made Tongue Restrictor Device (for the intermediate setting)

These diagrams show the insert used for the Intermediate setting -

A shows the insert in sagittal section on top of the manikin chin

B shows its actual intra-oral position

C shows its intra-oral position in lateral profile as indicated by a graphic insert

D has a ruler indicating relative size for the sketched top (oral surface) and side profiles of the insert. The insert is stable when positioned and easily removed as needed.

Participating anaesthetists were not told the order or nature of the test settings (i.e. easy, intermediate (mandibular insert) and difficult (tongue oedema)) although these could obviously not be blinded. We used block randomization with the order determined by blind drawing of previously marked cards. All four blades were used in each of the three settings so each participant performed 12 intubations. Successful tracheal intubation was confirmed by opening the flap at the front of the manikin neck.

The primary outcome measures were view obtained and time to intubate. Each participant was asked to grade the view according to Cormack Lehane Grade [9] and Percentage of Glottic Opening score. [10]Time to intubate was the time in seconds from when the anaesthetist picked up the laryngoscope to when the tracheal tube cuff was inflated.

Secondary outcome measures were success or otherwise, number of intubation attempts and degree of difficulty with laryngoscopy and intubation separately and user rated feeling of tongue compression. Failure was when intubation was not achieved or the time exceeded 120secs. An attempt was defined as forward thrust made with the tracheal tube or introducer with the intention of advancing it into the trachea. At the end of each laryngoscopy each participant was asked to score the degree of ease with laryngoscopy and intubation separately on VAS scale (0 to 100; 0 being extremely easy and 100 being extremely difficult) and their subjective tongue compression score (1 to 5, 1 being lowest and 5 highest).

The study data were analyzed using SPSS statistical package (version13). Time to intubate was analysed by Kaplan-Meier survival analysis (time to intubate as the time variable, successful intubation as the event). The difference between these curves was analysed using the log- rank test. Success rates were compared with Friedman's test and this was also used to compare: percentage of glottic opening (POGO); Cormack and Lehane grade; number of attempts and force used. Pairwise analysis was performed within the settings with McNamara's or Wilcoxon test as appropriate 'P' values ≤ 0.05 were considered to be significant.

Results

All 20 anaesthetists completed the study protocol. Anaesthetists who participated in this study were a combination of trainees with varied level of experience and Consultants anaesthetists with many years of experience. The median (range) anaesthetic experience of the participants was 6.7 (0.5 to 20) years. None of them had any prior clinical experience with any of the indirect devices tested in this study.

Table 3 shows comparisons between easy versus intermediate settings and intermediate versus difficult settings for individual blades. For Macintosh there is a consistent gradation that is true for almost all outcome measures (apart from number of successful intubations and number of attempts needed between easy and intermediate settings). Similarly Glidescope shows a parallel pattern of worsening of measures with increasing difficulty (except from number of successful intubations between each pair of settings). On the other hand Truview shows little change between easy and intermediate settings (apart from tongue compression and ease of laryngoscopy) but a worsening between intermediate and difficult (apart from number of successful intubations and number of attempts). Airtraq is different again in that it demonstrates Macintosh like worsening between easy and intermediate settings but it is the only blade to show no worsening from intermediate to difficult.

	Macintosh		**Glidescope**		**Truview**		**Airtraq**	
	Easy v Intermed	**Intermed v Difficult**	**Easy v Intermed**	**Intermed v Difficult**	**Easy v Intermed**	**Intermed v Difficult**	**Easy v Intermed**	**Intermed v Difficult**
Time to intubate (secs)	15-33 **	33-98 **	24-48 **	48-79 **	45-61 NS	61-103 **	23-73 **	73-75 NS
Success (n)	20-20 NS	20-6 **	20-18 NS	18-13 NS	20-17 NS	17-11 NS	20-18 NS	18-15 NS
POGO view	94-45 **	45-3 **	91-61 **	61-29 **	87-72 NS	72-30 **	100-85 *	85-93 NS
Cormack & Lehane	1.2-2.2 **	2.2-3.7 **	1.3-2 *	2-2.5 *	1.3-1.6 NS	1.6-2.8 **	1-1.3 *	1.3-1.3 NS
(VAS) Ease of laryngoscopy	7-43 **	43-93 **	15-41 **	41-65 **	20-35 *	35-69 **	6-26 **	26-22 NS
(VAS) Ease of Intubation	5-23 *	23-88 **	16-43 **	43-68 **	35-44 NS	44-74 *	12-47 **	47-63 NS
Attempts	1.1-1.2 NS	1.2-2.6 **	1.2-1.6 *	1.6-2.4 *	1.5-1.9 NS	1.9-2.3 NS	1.2-2.2 **	2.2-2.3 NS
Tongue compression	2-3.3 **	3.3-4.9 **	2-3.5 **	3.5-4.5 *	2-3.1 **	3.1-4.4 *	1.4-2.4 **	2.4-2.5 NS

Table 3 Between -settings comparisons for each blade

Values (apart from success) are means for each settings pair; significant differences- NS, * $p>0.05$, $p\leq0.05$, ** $p\leq0.005$

	Easy				**Intermediate**				**Difficult**			
	Mac	**GLS**	**TRV**	**ART**	**MAC**	**GLS**	**TRV**	**ART**	**Mac**	**GLS**	**TRV**	**ART**
Time to intubate (secs)	15 (11)	24(10) *	45 (26) *	23 (11) *	33 (16)	48 (32) ns	61 (32)*	73 (37)*	98 (35)	79 (39) ns	103 (27) ns	75 (36)*
Success (n)	20	20 (ns)	20 (ns)	20 (ns)	20	18 (ns)	17 (ns)	18 (ns)	6	13*	11 (ns)	15*
POGO view	94 (11)	91(12) ns	87 (19) ns	100 (1) *	45 (23)	61 (32) ns	72 (28) *	85 (30) *	3 (11)	29 (23) *	30 (33) *	93(9) **
Cormack and Lehane	1.2 (0.3)	1.3 (0.4) ns	1.3 (0.5) ns	1.0 (0) *	2.2 (0.5)	2 (0.8) ns	1.6 (0.6). *	1.3 (0.7) *	3.7 (0.6)	2.5 (0.9) *	2.8 (0.9)	1.3 (0.4) **
(VAS) Ease of laryngoscopy	7 (16)	15 (18) ns	20 (18)*	6 (9) ns	43 (26)	41 (23) ns	35 (25) ns	26 (25) *	93 (11)	65 (30) *	69 (28) *	22 (20)
(VAS) Ease of Intubation	5 (13)	16 (18)	35 (23) **	12 (13) *	23 (19)	43 (31) *	44 (33) **	47 (32) **	88 (25)	68 (29) ns	74 (28) ns	63 (30) *
Attempts	1.1(0.2)	1.2 (0.5) ns	1.5(0.8) ns	1.2 (0.5) ns	1.2 (0.5)	1.6 (0.9) ns	1.9 (1) *	2.2 (1.1) *	2.6 (1.3)	2.4(1.3) ns	2.3 (1) ns	2.3 (1.3) ns
Tongue compression	2 (0.9)	2 (0.9)	2(0.9) ns	1.4 (0.5) *	1.4 (0.5)	3.5 (1.1) ns	3.1 (1.1) ns	2.4 (0.9) **	4.9 (0.2)	4.9 (0.9) ns	4.5 (0.8) *	2.5 (0.9) **

Table 4 Between-blade comparisons (relative to Macintosh) for each setting

Values (apart from success) are means for each blade; significant differences (below) are in comparison to Macintosh for each setting

(ns=p >0.05,*p ≤ 0.05, **p ≤ 0.005)

Table 4, shows that in the easy setting Macintosh was superior in terms of intubation times. Truview scored worse for both ease of laryngoscopy and intubation. Both Glidescope and Airtraq had worse ease of intubation but Airtraq provided a better view and with less tongue compression. In the intermediate setting Macintosh was again superior in terms of time required to intubate and number of attempts (except for Glidescope). Ease of intubation was better than for all the other blades. However both Airtraq and Truview were better in terms of the view obtained. Airtraq was again better in terms of the tongue compression score and this time also better for ease of laryngoscopy. For the difficult setting, Macintosh had poor scores in all measured outcomes. Airtraq was superior to Macintosh in all respects apart from number of attempts. Glidescope was more successful than Macintosh with better views and ease of laryngoscopy scores. Truview provided better views and ease of laryngoscopy with less tongue compression.

Additional post hoc comparisons were made between the indirect laryngoscopes in the difficult setting where Airtraq proved to be superior to both Glidescope and Truview in providing a significantly better view, ease of laryngoscopy and less tongue compression. However ease of intubation was not significantly better than either Glidescope or Truview.

Discussion

Certain design constraints in this sort of study are inevitable. Anaesthetists are familiar with Macintosh laryngoscopes and these devices cannot be blinded in use. Equally it was not considered possible to blind the settings in our model of progressive difficulty. On the other hand, all the indirect laryngoscopes were treated equally in that none of the participating anaesthetists had prior exposure to them. Simulation studies of difficult laryngoscopy, although popular in recent years [11-19], have been criticised as to whether the results represent the real world.[1]On the other hand, because patients are heterogeneous, clinical trials will always have their own limitations (i.e. whether the sample is truly representative). In our view there are two important uses for simulation, firstly in trying out devices before using them in humans (e.g. how easy they are to use) and secondly to test various mechanical or functional hypotheses because with a manikin we can impose specific reproducible test conditions. The native manikin settings (resting and tongue oedema) for SimMan are well validated in previous studies. [20-24]In designing this model we wanted to develop an intermediate stage of difficulty based on some of the most important limitations for Macintosh laryngoscopy, i.e. mandibular space reduction and tongue compression. The insert we designed to this end was chosen as a result of a pilot study comparing similar prostheses of different size. It is easily manufactured and reproduced. It successfully withstood repeated insertions into and out of the manikin and multiple laryngoscopies. For the Macintosh laryngoscope our model provided a consistent gradation of difficulty for all measures between the three settings. In that sense the insert was validated as a useful intermediate setting.

In deciding which laryngoscope blades to use for this study we were interested in comparing some of the newer indirect laryngoscopes with Macintosh. Firstly we were interested in shape / angulation characteristics and secondly that indirect laryngoscopes have been suggested to fall into two broad classes - either "steering" or "channel" devices.[15] Airtraq was our choice of channel device and Glidescope was our choice for steering device. We have been interested for some time in angled blades and reported previously on a comparison between Truview and the original Belscope angled blade, which could also be used with a prism and as such was one of the first indirect viewing laryngoscopes.[25-26] (Truview also happens to be a steering in type.)

From our insert pilot studies we had anticipated some failures with Macintosh in the intermediate setting due to the reduced view. However user familiarity and ability to cope with a reduced view using a Macintosh laryngoscope meant there were no failures. A positive feature of Macintosh direct laryngoscopy is that it provides an all-round view, making it particularly amenable to use with a bougie. Indirect laryngoscopes on the other hand didn't show 100 percent success or were not faster in the intermediate setting despite a significant improvement in the view. This finding is similar to previous studies wherein better view was not equivalent to an easier intubation (i.e. ease of laryngoscopy does not equate with ease of intubation). [17-19]It should be considered to be the main negative feature of indirect laryngoscopy.

This feature has been suggested to vary according to whether an indirect laryngoscope is a channel device (e.g. Airtraq or Pentax AWS) or a steering device (e.g. Glidescope or Truview EVO2) [15, 21, and 27]. In our study Glidescope (our typical steering device) showed no advantage in the easy and intermediate settings, in fact scored worse for ease of intubation in the intermediate setting despite the ease of laryngoscopy being the same as Macintosh. This is similar to findings reported in study by Savoldelli et al. where pharyngeal obstruction and cervical spine rigidity scenarios were used to compare Glidescope with Macintosh.[28] In order to overcome this difficulty with intubation various tube directing manoeuvres have been suggested including use of different types of stylet and altering their angulation.[24,29-30]For our study, participants were asked to use the rigid GlideRite stylet only and no modification of the stylet was allowed. (The tube was loaded onto the stylet and used as per the manufacturer's instructions.) It is worth noting, however, that other studies have shown that a standard malleable stylet performed equally well compared with GlideRite [31] and better than the Flex-It stylet. [32]

Channel devices may have a natural advantage over steering devices because problems directing the tube towards the larynx are facilitated by the channel itself. [21, 27-28]In our study Airtraq was the most successful device in the difficult setting, however it did require longer intubation times in the easy and intermediate settings. This is suggested to be due to emergence characteristics of the tracheal tube from the channel and relevance of the distance of the tube tip from the inlet. [33-34] Alternative insertion techniques and manipulations of the Airtaq have been described to improve intubation times. [34-35]

As far as testing the blades in the model were concerned, the patterns of change in the study parameters with worsening laryngoscopy conditions were interesting. The model was designed to produce worsening of all parameters for Macintosh laryngoscopy and it did. However Glidescope was the only indirect laryngoscope to show similar worsening to Macintosh. Truview showed lesser worsening in the intermediate setting but similar worsening for the difficult setting. Airtaq was unique in the sense that after initial worsening in the intermediate setting, it showed no further worsening in the difficult setting. We suggest that this implies similar functionality for Glidescope compared with Macintosh and totally different functionality for Airtraq. From the point of view of individual blade comparisons, Truview gave a better view than Macintosh in the intermediate setting even though this was at the cost of increased number of attempts. Equally in the difficult setting it gave better views and an easier laryngoscopy than Macintosh but not an easier intubation. On the other hand, Airtraq gave better views than Macintosh in the intermediate setting and was the most successful laryngoscope and with faster intubation times in the difficult setting. This was achieved with significantly less tongue compression in all the settings. It was also noteworthy that the mean POGO score for Airtraq in the difficult setting was almost identical to that for Macintosh in the easy setting.

Our idea was to compare the chosen devices in the context of their functionality which the intermediate difficulty setting allowed. As a result we can state that Macintosh should be considered as similar to Glidescope because of the sequence of change between the easy, intermediate and difficult settings. Using similar arguments comparing Airtraq with Macintosh allowed us to conclude that it is quite different. Airtraq may therefore represent an important step in the right direction in dealing with the main limitations of the Macintosh blade. Even with reduced mandibular space it appeared to reduce the need for tongue compression while offering improved views. Macintosh should still be seen as having advantages in our intermediate setting but it remains to be seen whether this can be explained entirely on the basis of familiarity with the device in question. Our model also suggests that Glidescope and to some extent Truview are functionally similar to Macintosh. Although others have had the same results as ours for the difficult (tongue oedema) setting it is the intermediate setting which allows a convincing argument as to the basis for these differences.

We suggest that this new insight will change the perception as to how indirect laryngoscopes should be analysed. The new optical systems should be expected to have an obvious advantage even if there is some cost in terms of directing the tube into the larynx. However many different shapes of blades have appeared with no justification as to why the particular shape was chosen. It is therefore reasonable to question whether a better optical system is actually matched by any improvement in the blade design. Indeed it is essential to question whether optical improvements could even compensate for and overshadow a change in blade shape that was functionally worse than that of Macintosh.

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4.2 Post hoc analysis: DELI Index (Difference in Ease of Laryngoscopy and Intubation)

This section presents additional finding not reported in the published paper (section 4.1). After completing the laryngoscopies, each anaesthetist was encouraged to comment on usefulness or otherwise of the individual blades. These free text comments were interesting because of the variety of views expressed. Truview received the most negative comments though Glidescope seemed to be commented on more favourably than might be expected from the study results. The fact that it was functionally the most Mac-alike instrument (i.e. it may have felt more like what they were used to) and that it was the only one with its own monitor system may have helped. By contrast Airtraq seemed to be given less credit that the results suggest it deserved. Two anaesthetists commented that its bulk could be a potential disadvantage in patients with limited mouth opening.

The obvious Macintosh advantage is the general consideration that "if you can see it you can intubate it", whereas for indirect laryngoscopes a commonly reported finding is difficulty experienced with achieving intubation despite an adequate view. To quantify this difference we looked at the distribution of VAS scores for laryngoscopy and intubation. By way of post-hoc analysis we used a simple index resulting from the difference between the two VAS scores, ease of laryngoscopy and intubation, for each of the blades. We called this novel index as "DELI"- Difference between Ease of Laryngoscopy and Intubation. Figure 40 shows the distribution of DELI scores for each blade in each setting.

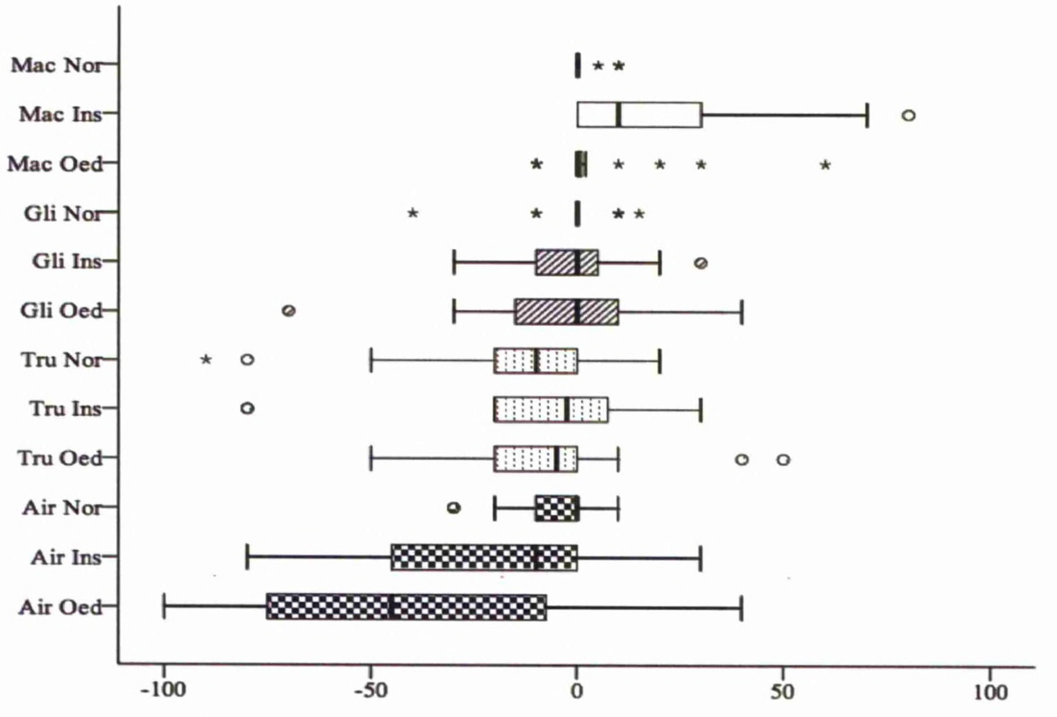

Figure 39 Boxplots for the distribution of DELI scores for each blade in each setting.

Differences between VAS scores for ease of laryngoscopy and ease of intubation are represented as boxes showing the inter-quartile range, with thickened lines for the median, whiskers extending to highest and lowest values, outliers shown as circles and extremes as stars. [A score of -100 means laryngoscopy was easy (0) but the intubation was rated most difficult (100); whereas a score +100 means laryngoscopy most difficult (100) but the intubation was rated easy (0). A score of 0 means laryngoscopy and intubation were equally easy or difficult.]

To further analyse this data we tested each distribution to see whether the mean values were significantly different from zero (using a one sample t-test). While Macintosh in the easy setting was not centred on zero by this test, there were 16/20 instances where the actual value was zero. It was centred on zero for the difficult setting. In the intermediate setting Macintosh was unusual because the mean (20.25) was clearly shifted to the right. (In other words, despite the difficulty in obtaining a view, the intubation was relatively easy.)

For Glidescope all three settings were centred about zero. If the extreme (-90) and outlier (-80) in the easy setting were ignored, all the Truview settings were again centred about zero. With Airtraq none of the means were centred on zero and as difficulty increased, so the means shifted leftwards (-6, -21.25, -41.75), i.e. the intubation was more difficult than might have been expected for the view. Kruskal-Wallis analysis showed that there were significant differences between blades overall but not between settings. On Mann-Whitney pairwise comparisons Macintosh differed from Truview and Airtraq in all 3 settings ($p<0.05$) and from Glidescope in only the insert setting ($p<0.005$).

Discussion

Difficulty with intubation despite an adequate view needs to be considered relative to any important advantage over Macintosh. We suggest that the "DELI" score (i.e. differences between view obtained and ease of intubation) may prove to be a useful measure for this reason. With Macintosh, even in the Intermediate setting, difficulty in gaining a view was not at the expense of difficulty with intubation. In other words, even this right shift could be seen as a positive feature of Macintosh laryngoscopy i.e. even when getting a view was a problem, intubation was still relatively easy. Any suggestion of a leftward shift, however, means progressively more difficulty with intubation despite an acceptable view. DELI should prove to be a simple measure of such considerations and, for example, whether a design modification also leads to an improved DELI score.

4.3 Post hoc analysis: Overlay Photographic Methodology

In order to help explain any differences in blade performance, one of the authors attempted to reproduce the mean POGO score for each setting with each of the blades. Laryngoscopies were recorded with a lateral photograph at the time of maximum laryngeal exposure. Each photograph was then used to as the basis for an overlay diagram to demonstrate the relative positions of the laryngoscope blade, laryngeal inlet, internal mandibular outline and, where appropriate, insert position. These diagrams were constructed to help interpret the main study results.

The overlay technique is used here to determine the position of blade tips when they would not normally be visible. In this case a median-sagittal plane of a manikin is considered to describe (in 2-dimensional sense) the relationship of an inserted laryngoscope blade tip to the laryngeal inlet. (In the Laerdal manikin, the laryngeal position is partly visible externally when the "neck skin" is removed and an aperture beneath it allows inspection of the trachea and larynx.) The technique requires a number of digital photographs: the primary image of the situation of interest, in this case the act of maximum exposure of the larynx at laryngoscopy, and then one or more secondary images to acquire enough information about the laryngoscopes to be able to overlay their outlines or positions onto the primary photograph.

All of the photographs were with objects positioned in the same (median sagittal) plane with the camera positioned at exactly the same distance from and at right angles to this plane. The (primary) laryngoscopy photographs should also be taken so as to maximize the amount of the blade handle visible to the camera. For the secondary images the laryngoscopes were photographed just above the manikin head and neck in the same median sagittal plane. These secondary images were loaded into a computer graphics program (CorelDRAW^{TM}) for processing. The laryngoscope blade outline shapes were reproduced by Bezier line drawing at high magnification for accurate reproduction. The shape outline was then transposed onto the laryngoscopy photograph. At this stage the object usually need to be translated and rotated. To do this without distortion the object was placed within a suitable sized circle with at least three edges of the object touching the perimeter of the circle. The object and circle are then "grouped" for easy rotation and translation. The laryngoscope outline was manipulated so as to position exactly over the handle of the primary laryngoscope shape.

For the laryngeal inlet positioning a specially deformed paper clip was used. The clip deformation allowed an outstretched end to point at parts of the larynx through the aperture in the neck under the collar. Three secondary images were used: a free space image of the clip; the free end of the clip pointing anteriorly and then posterior edges touching the vocal cords. (The clip was held in place in the midline using a small magnet positioned on the neck.) The graphics program was used to outline the shape of the clip in free space and then this shape was then used to identify the anterior and posterior points of the laryngeal inlet so that a suitable line could be drawn on the primary (laryngoscopy) image.

For the insert shape, this was positioned immediately above the lower lip for its free space shape outline and photographed with its upper surface in line with the manikin lower incisors, again in the median sagittal plane. With suitable translation and rotation along the line of the lower incisors, it was then easy to overlay the position of the insert and use the insert anterior surface as an indicator for the position of the internal midline surface of the mandible.

Resulting images and their interpretation

Figures 41, 42 and 43 show the Overlays for Macintosh, Truview, Glidescope and Airtraq in all 3 settings reproduced in Laerdal Sim Man.

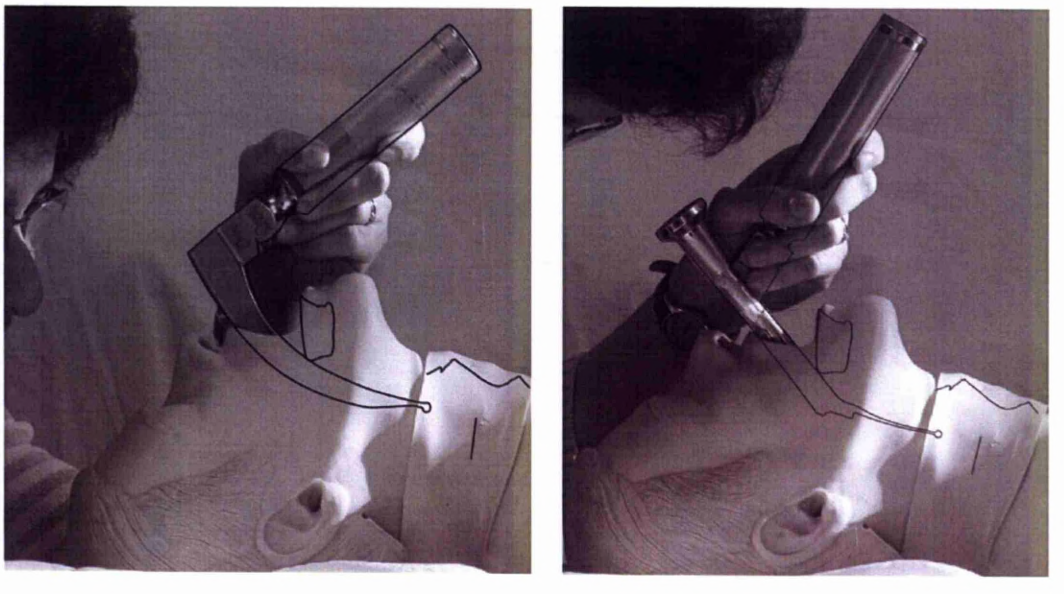

Figure 40 Overlay 1: positioning of Macintosh and Truview in the intermediate setting.

Macintosh and Truview blade tips are seen with respect to the inlet and the custom-made insert (drawn in median sagittal section). A single straight black line represents the laryngeal inlet. The line on the neck represents the anterior surface of the manikin underneath its "neck skin".

Overlay 1 shows that tongue displacement with Macintosh and Truview were slightly different as the distances from the blade tip to the front of the neck were 2.7 and 3.0 cms for Macintosh and Truview respectively. Macintosh had slightly better tongue displacement compared with Truview. Despite this Truview's optics resulted in a better view (mean POGO's 72 versus 45 respectively). So here Truview's optics compensated for its worse tongue displacement profile. Furthermore our analysis showed that, for the Difficult setting, Truview had a more anterior blade position than Macintosh (i.e. both the optics and position were better).

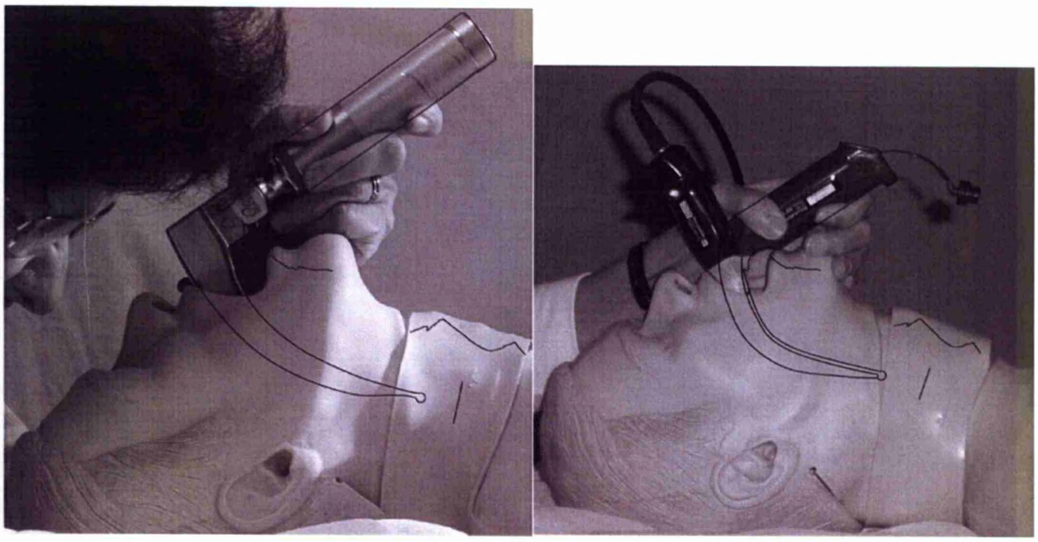

Figure 41 Overlay 2: positioning of Macintosh and Glidescope in the difficult setting

Overlay 2 showed that Glidescope had identical blade tip positioning as compared with Macintosh in the difficult setting, however the optical system resulted in a better view (mean POGO score for Macitosh 3 versus 29 for Glidescope).

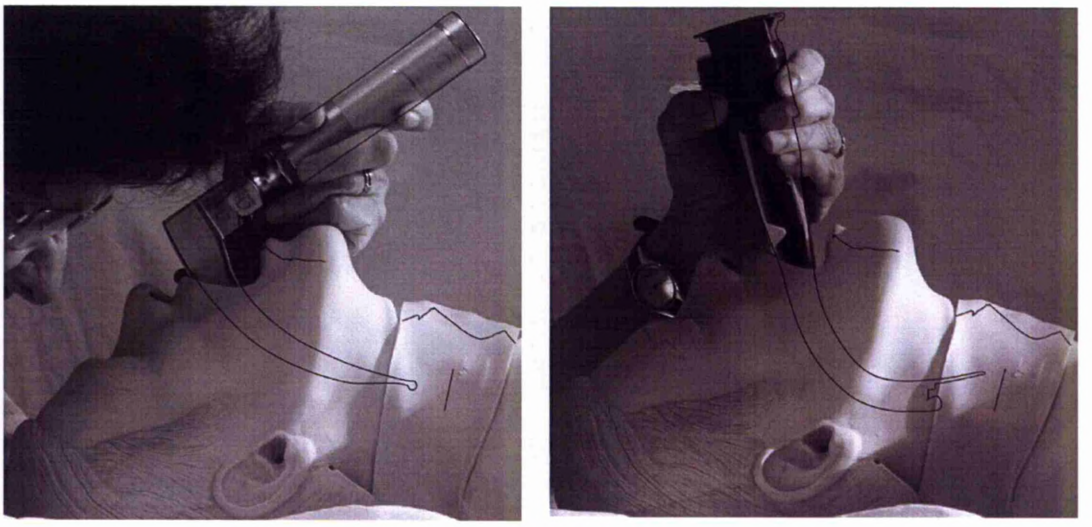

Figure 42 Overlay 3: positioning of Macintosh and Airtraq in the difficult setting

Overlay 3 shows a line inside the chin representing the internal surface of the ramus of the mandible. The space anterior to the Airtraq blade is greater than that for Macintosh yet the mean Airtraq POGO score was 93 whereas with the much smaller space with Macintosh the mean POGO score was 3. For an instrument that seems rather bulky this result may not be entirely obvious. However this is consistent with the earlier force results (Table 3) in that the view obtained with Airtraq was with limited force requirement (i.e. there was less tongue compression). Overlay 3 also suggests that in the Difficult setting, the Airtraq blade tip is slightly more anterior but more importantly, the optics are ideally positioned to allow a full view of the inlet as opposed to almost no view with Macintosh.

The overlay method used here was further refined in the later clinical study (Section 5) and the interpretations of the graphics changed with increasing experience in using this method.

4.4 Conclusions

This section detailed functional comparison of indirect laryngoscopes with Macintosh in a model of graded difficulty created in the Laerdal Sim Man.

The intermediate level of difficulty due to the insert provided good evidence for a consistent gradation of difficulty with intubation, from easy to intermediate to difficult.

Macintosh had no failures in the intermediate setting and was also superior in terms of time taken to intubate. Intubations with Indirect laryngoscopes on the other hand were not faster despite giving a better view. This positive feature of Macintosh is suggested to be due the "all round view" down to the laryngeal inlet.

Glidescope showed comparable worsening measures of difficulty as grade of difficulty increased. In this sense Glidescope was functionally similar to Macintosh.Truview showed less worsening of measures of difficulty and in the difficult setting gave better view than Macintosh.

Airtraq was functionally unique and also the most successful device in the difficult setting. Airtraq achieved better views with significantly less force needed (i.e. less tongue compression).

To quantify the difficulty associated with intubation despite an adequate view using indirect laryngoscopes, a new index "DELI" was proposed. This is based on differences between the VAS scores i.e. VAS for ease of laryngoscopy (0-100) minus VAS for ease of intubation (0 to 100).Difficulty with intubation despite an adequate view needs to be considered relative to any advantage over Macintosh. The "DELI" score may prove to be a useful measure in this connection. With Macintosh, even in the intermediate setting, difficulty in gaining a view was not at the expense of difficulty with intubation. In other words even this right shift in DELI scores could be seen as positive feature of Macintosh laryngoscopy i.e. intubation was relatively easy despite a suboptimal view. Any suggestion of leftward shift however means progressively more difficulty with intubation despite an acceptable view. Airtraq exhibited such a left shift in DELI scores.

Using our Overlay technique it was possible to demonstrate the relative positions of laryngoscope blade, laryngeal inlet and neck skin. The technique showed potential in terms of explaining the laryngeal view obtained with respect to blade tip positions (functional properties) and also in determining the optical advantages versus functionality of indirect laryngoscopes.

Overlay analysis showed that Glidescope had identical blade tip positioning compared with Macintosh in the difficult setting, but the optical system resulted in a better view. Truview in the intermediate setting had slightly worse tip positioning but its optics still compensated for this worse functionality and provided a better view than Macintosh.

Airtraq positioning in the Overlay was quite different from others. Minimal tongue compression was seen overall and was even more evident in the difficult setting. Views obtained in this setting were significantly better than for the other IDLs and at no extra cost in terms of force needed.

Section 5 Clinical Overlay Trial comparing IDLs

This section concerns a clinical trial titled - Comparison of Indirect laryngoscopes with Macintosh with particular relevance to their functionality.

The aim of this study was to further understand mechanisms underlying direct Macintosh laryngoscopy and make "functionality" comparisons with Glidescope, Truview and Airtraq indirect laryngoscopes. Thirty-six patients, scheduled for elective tracheal intubations as part of their clinical care, were recruited to this study. Each would have three consecutive laryngoscopies, Macintosh first then two of the three indirect laryngoscopes according to a block randomization, which would result in 24, paired comparisons of Macintosh with each indirect laryngoscope. Pre-operatively a sequence of measurements and surface markings were performed and then in theatre, standardised lateral neck photographs were taken at the moment of maximum laryngeal exposure for each of the three laryngoscopies. At a later time, all the lateral photographs were processed using the "Overlay technique" described previously in section 4. Subsequent analysis was based on the Mathematical model used by Charters for osseous factors in difficult intubation [59]. A novel system for detailed analysis evolved that proved accurate and reproducible and for the first time allowed detailed comparison of functional versus optical advantages of indirect laryngoscopes relative to Macintosh laryngoscopy.

5.1 Introduction

Mechanisms of Macintosh laryngoscopy and osseous factors involved in difficult intubation have been well studied in the past. Based on X ray laryngoscopy studies Horton et al. suggested an "Ease of Intubation Angle" linking internal mid-point of mandibular symphysis, upper incisors and a point on the anterior airway just above larynx.(60)Bellhouse and Doré had also considered space behind the mandible as a link to predicting difficult intubation. (36)This space is needed for tongue displacement to permit a direct view down to the laryngeal structures. In addition, the tip of the laryngoscope blade needs to contact and move the hyoid bone (and hence elevate the epiglottis) to complete the visualization of the laryngeal inlet. This contact with the hyoid is very dependent on the space available for tongue displacement and an index of difficulty based on the space available behind the mandible has shown significant correlation with the degree of difficulty. This has been described as 'final common pathway' for difficulty with inubation. (60) Space behind and below the mandible has also been linked to analysis of laryngoscope blade shape (8, 36, 59-61). Others have used a theoretical analysis of blade shape described by Marks et al. for performance analysis of many different laryngoscope blades (44, 62).

An increasing number of new indirect viewing rigid optical laryngoscopes have come onto the market in the last few years that make indirect visualization of the larynx feasible. They appear to have been based on the strengths of the relevant companies and involve either camera systems with digital image processing or enhanced optical systems. At the same time blade shape changes have been introduced but without any obvious explanation as to why these changes were thought necessary and whether there was any obvious benefit in terms of "functionality" relevant to the original

Macintosh shape. Indeed it would be reasonable to question whether an improved optical arrangement could hide an inferior blade shape. Primary aim of this study was to determine whether new indirect devices are any better in terms of the view obtained than standard Macintosh.

In planning this study the main issues that were considered were:

1. Do the indirect devices need tongue displacement and the hyoid tip contact to the same degree as Macintosh blade?
2. Is there any difference in this tongue displacement profile?
3. Do the differing lengths of distal straight segment of these indirect laryngoscopes (difference explained in section-2) have any implication for the view obtained?

A clinical trial to comparing three indirect laryngoscopes (Truview EVO2, Glidescope Video laryngoscope and Airtraq) with Macintosh laryngoscope was designed where the "Overlay technique" would be used to compare blade positions in use (i.e. an outline of the relevant laryngoscope blade would be superimposed on a standardized lateral photograph taken at the moment of maximal laryngeal exposure). Each patient would have an initial Macintosh laryngoscopy followed by two out of the three indirect devices selected in a block randomization. In Section 2 their respective distal straight segments were shown to be: Glidescope, 6 cm; Airtraq, 3.8cm and Truview EVO2, 5.5 cm. The analysis of the overlay images was planned to relate to the mathematical model for osseous factors in difficult intubation [59].

5.2 Methods

Approval for the study was obtained after submission to South Sefton Research Ethics Committee. Following explanation and time to reflect, written consent was obtained from thirty-six ASA physical status I to III patient undergoing routine ENT surgery where tracheal intubation was part of the planned management of their clinical care. None of the patients included had any airway pathology or obvious anatomical deformity.

Preoperatively, a sequence of external measurements and markings were undertaken. The general measures consisted of height (cm), weight (kg), BMI and arm span (cm). For the head and neck, inter-incisor distance (cm), inter-condylar distance (cm) and ability of jaw protrusion (behind incisor=0, on level=1, in front of incisor=2) were recorded. A calliper measure ("ExtCond-to-IntSym") was made of the distance (cm) from the surface of the mandibular condyle to the mid-point of the internal surface of mandibular symphysis. Neck extension (degrees) was measured using an angle finder device against a reference horizontal line drawn on the side of the face forward from the external auditory meatus. Superficial marks were then drawn immediately anterior to the external auditory meatus and the sternal notch.

In theatre, once patient was anaesthetized, the crico-thyroid membrane was marked for identification on the lateral photographs. The anaesthetic technique was standardized with all the patients given Fentanyl then Propofol for induction followed by Vecuronium for muscle paralysis. The intensity of neuromuscular blocked was monitored and laryngoscopy was attempted only after adequate paralysis was present. Head and neck positioning was standardized using a previously described standardised posture [63]. At all times care was taken to maintain a centred head position, i.e. without any lateral rotation. A dental roll was positioned underneath the upper lip to ensure that the upper incisors remained clearly visible on the lateral photographs.

The first laryngoscopy was always with the Macintosh blade. A standardized lateral photograph of the patient's head and neck was taken at the moment of maximum laryngeal view and the anaesthetist reported the POGO score. At the same time, a photograph was also taken from the foot end of the trolley to confirm that the head position had not rotated laterally. (In a small number of cases this was used to refine the blade images in the overlays to compensate for any rotation of the blade handle that had occurred.) The second and third laryngoscopies were performed with an indirect device chosen by block randomization. For each a lateral and foot end photograph was taken at the moment of maximum laryngeal view and POGO reported. Screen shot recordings of the laryngeal views were also obtained for each of the study devices. After the third laryngoscopy recordings were completed, the patient's trachea was intubated with this same device.

Processing of the lateral photographs (taken at the moment of maximum laryngeal exposure) started with importing the digital photographic/video images into Corel Draw (version 13) graphic software so that the superimposed laryngoscope blade shapes could be added (as described in Appendix B). From the overlays, the positions of tip of laryngeal blade relative to the surface markings made preoperatively could be determined.

For the analysis of these images an outline of the features of interest was produced using the Bezier curve drawing tool in the software. The resultant image with the superimposed laryngoscope blade could then be printed out at life size magnification as seen in figures 43 and 44.

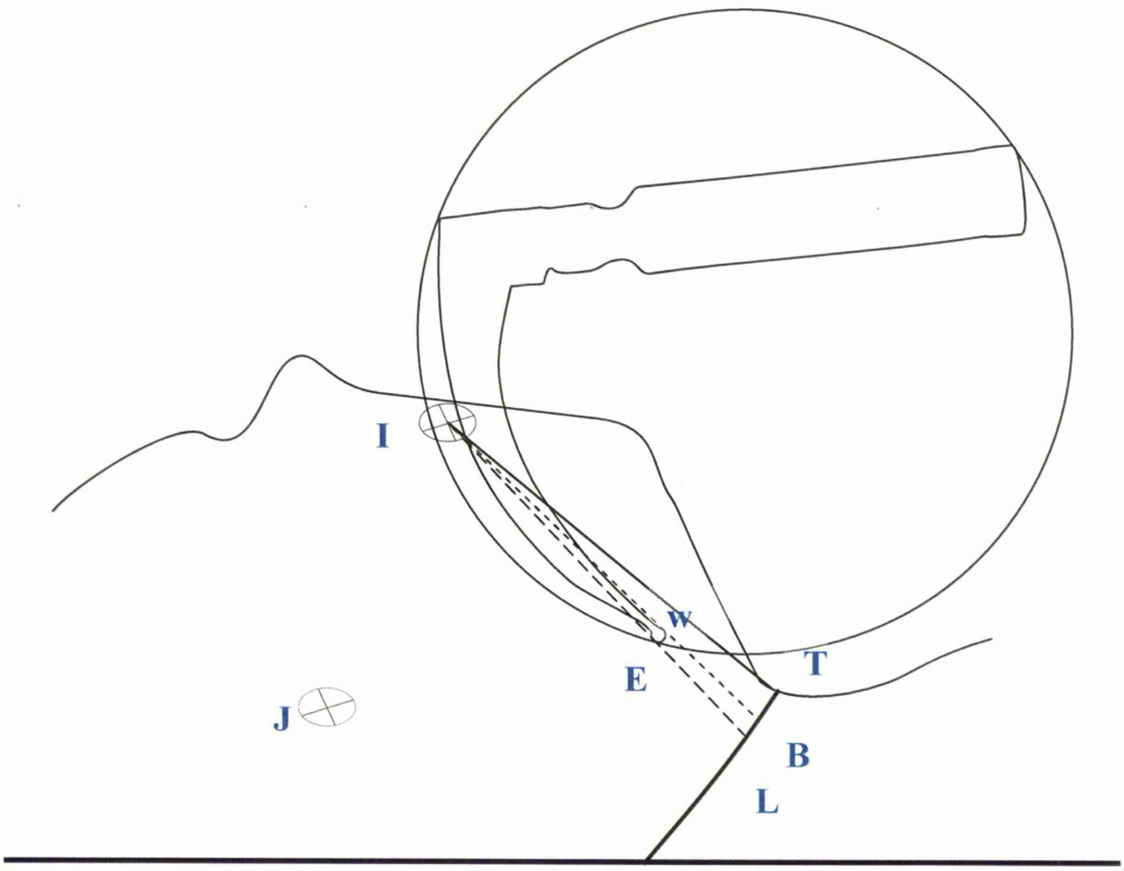

Figure 43 Macintosh overlay to indicate effective eye position at the tip of the blade

Points marked on overlays are: I = Incisor point, T = anterior end of laryngeal line, J = mark in front of external auditory meatus and w = most forward point on tip of the blade. E = the effective eye position, IT = Anterior airway line, IL = eyeline deviation line, IB = line to represent how far the blade is pushed further back from IT.

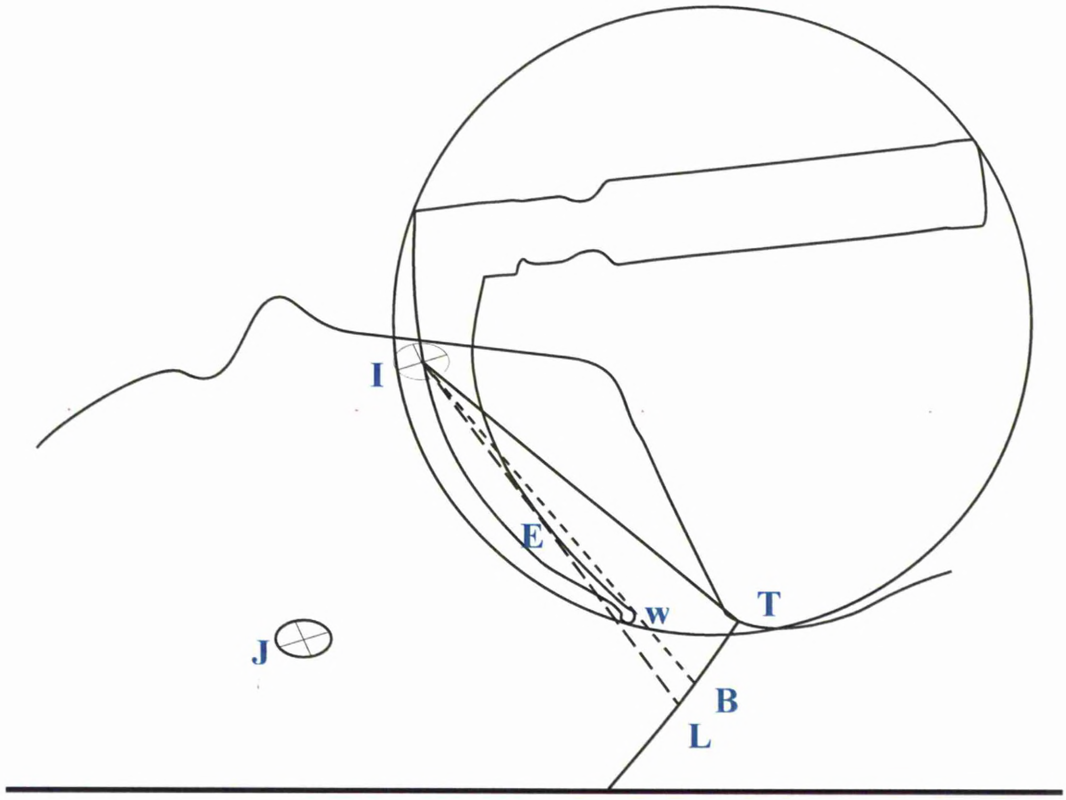

Figure 44 Macintosh Overlay to indicate effective eye position relative to the blade tip

Figure 44shows that the eyeline does not reach the tip of the blade because it is deflected by the curve shape at point E. The following points were marked on the overlays:

I = point where blade rests on incisors

T = pre-marked Cricothyroid membrane point

J = mark in front of external auditory meatus

w = most forward point on the tip of the blade.

E = the effective eye position which could be at the tip (figure 44) or anywhere alongthe blade curvature (figure 44)

IT = IT represents the ideal straight line view to the laryngeal inlet and is referred to as 'anterior airway line.'

IL = The line drawn from incisor point along a tangent to the curved under-surface of the blade and passing through the most limiting forward point of the blade intersects laryngeal line at point L. IL represents the eyeline deviation from the ideal 'anterior airway line'

IB = Line IB represents how far the blade is pushed back away from line IT.

Confirming the lengths of the laryngoscope blade and its handle checked the accuracy of the sizing of the printed images. Next the following measurements were taken from the printed image (distances measured in centimetres and angles in degrees):

1. Lengths- IT, Iw (depth of Insertion of blade, DOI), percentage depth of insertion, the distance between tip of the blade (w) and skin surface keeping parallel to laryngeal line, distance ET
2. Angle TIL to give an indication of amount of eye-line deviation from ideal anterior airway line.
3. Angle TIB to give an indication of how far the blade is pushed back from IT
4. Angle BIL to give indication of the space occupied by the blade

The derived measures for the indirect laryngoscopes were slightly different as shown in figure 45 where Glidescope is depicted as an example.

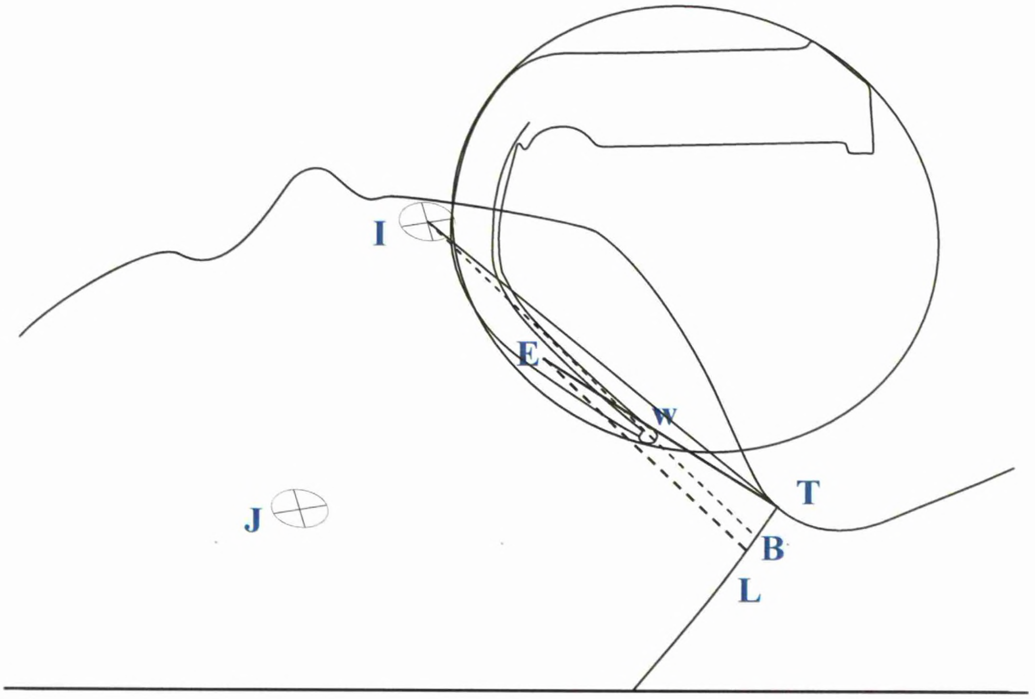

Figure 45 Line drawing of Glidescope Overlay

Points on the overlay are: I = Incisor point, T = anterior end of laryngeal line, J = front of the external auditory meatus, w = most forward point on blade tip, E = Effective eye position where the camera is situated at a distance equal to distal straight segment (For Glidescope the camera is at 5.5cm, Truview 5.5cm and Airtraq 3.8cm), ET= effective eyeline, IT= anterior airway line.

For IDLs, several measures were made from these life size printouts.

1. Lengths IT, ET, Iw (depth of Insertion of blade, DOI), the distance between tip of the blade (w) and skin surface keeping parallel to the laryngeal line and IE
2. Angle TEL was considered positive when below the ET line and negative when above it. (This angle is equivalent to angle TIL i.e. eyeline deviation angle from anterior airway line.)

3. Angle ETL

In the second stage of the analysis an attempt was made to compare the nature of tongue displacement. The novel approach was developed, based on the previous observation by Charters, [59] that the jaw line JS, usually intersected the line IT (at intersection point X), 2/3 of the way up from T. In that work, S was the internal mid-point of the mandibular ramus, but for this study X was a point on IT 2/3 of the way up from T and extension of the line JX to the skin described the point S which was used as a proxy for S. For Macintosh and all the indirect laryngoscopy images it was then possible to construct diagrams in Corel Draw where four specific areas could be identified and colour-coded as in figure 46. See Appendix C for details.

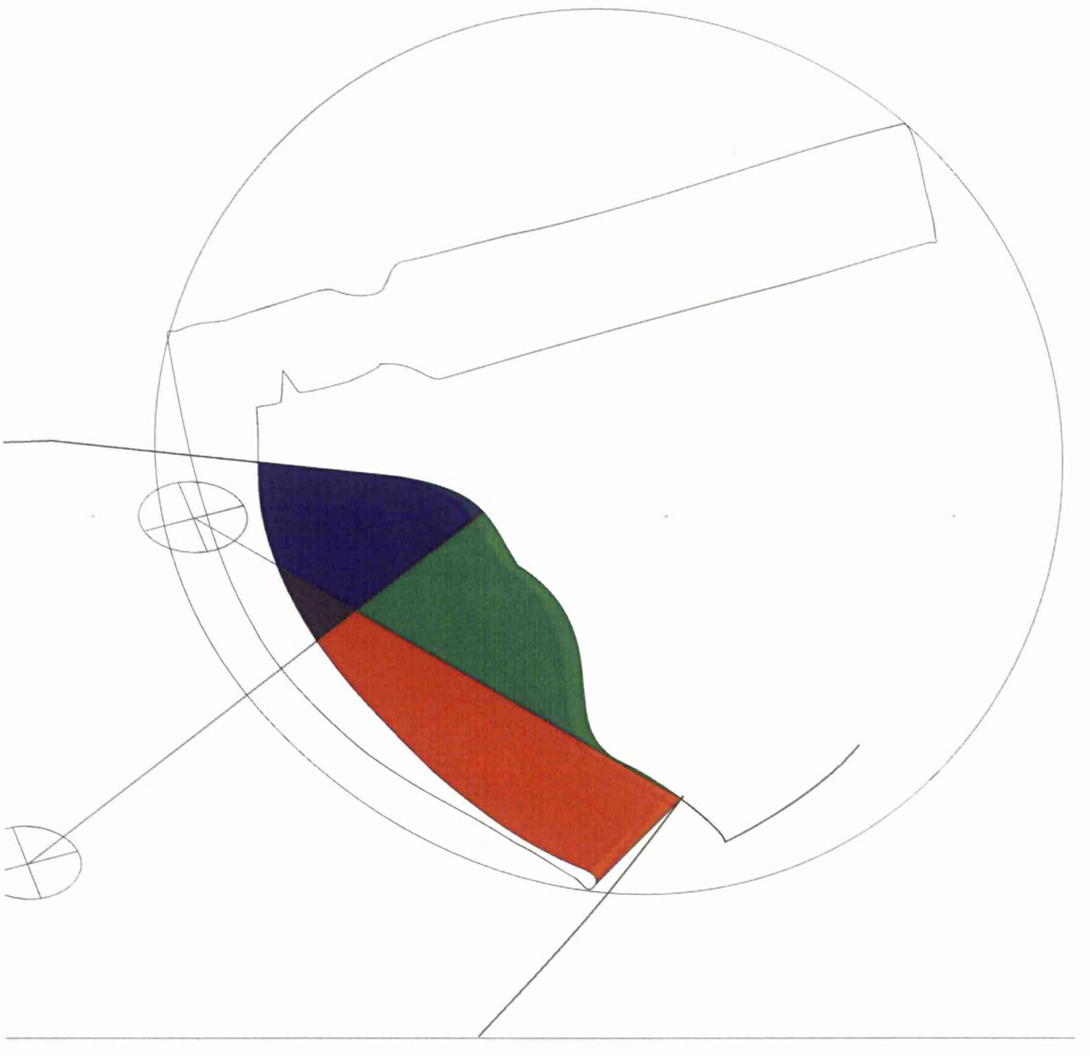

Figure 46 Overlay of Macintosh laryngoscopy with individual area mapping.

The size of each of these areas was determined by exporting the life size vector images from Corel Draw into Corel Paint to get life size tiff images. The tiff images were then imported with the individual colour coded components for specific coloured area measurements usingAnalyzingDigitalImages software, Digital Earth Watch software. [64]

The final stage of the methodology was to try and understand what factors influenced this tongue distribution and for this all the factors that might be relevant in the pre-operative measurements and the overlay diagrams were considered and tested by standard statistical analysis. Variables tested were:

1. Distance of blade tip from neck skin
2. Depth of insertion of each blade and percentage depth of insertion
3. IT distance for each blade
4. Eyeline deviation angles- TIL, TEL
5. Angle BIL
6. Angle ETL
7. Distance IE and ET
8. Angles IET and EIT
9. All Preoperative measurements
10. Area measurements in each overlay
11. Line measurements in each overlay
12. Angular measurements in each overlay
13. F value

All these variables were correlated to POGO scores as well as combination area measurements. In overall comparisons there would be 36 Macintosh and 24 Glidescope, Truview and Airtraq data points. For this Regression analysis and scatter plots were used. Variables were tested for individual blades as well for blade-pairings in each patient (Macintosh versus each IDL would be resulting 24 paired data points whereas 12 pairs for IDL vs IDL. Paired blade comparisons were done using Student t tests.

5.3 Results

Thirty-six patients completed the study protocol. No view could be recorded in one case while using Truview EVO2 due to equipment failure.

Results will be presented in 2 sections in the following order:

- **A.** Analysis of variables influencing laryngoscopy view (POGO)
- **B.** Blade differences relative to these same variables
- **C.** Correlations of interest
- **D.** Case demonstrating Peardrop effect

Section A

This section at first looked at overall POGO scores. POGO for Airtraq was significantly larger as compared with Macintosh, Truview and Glidescope ($p < 0.001$).

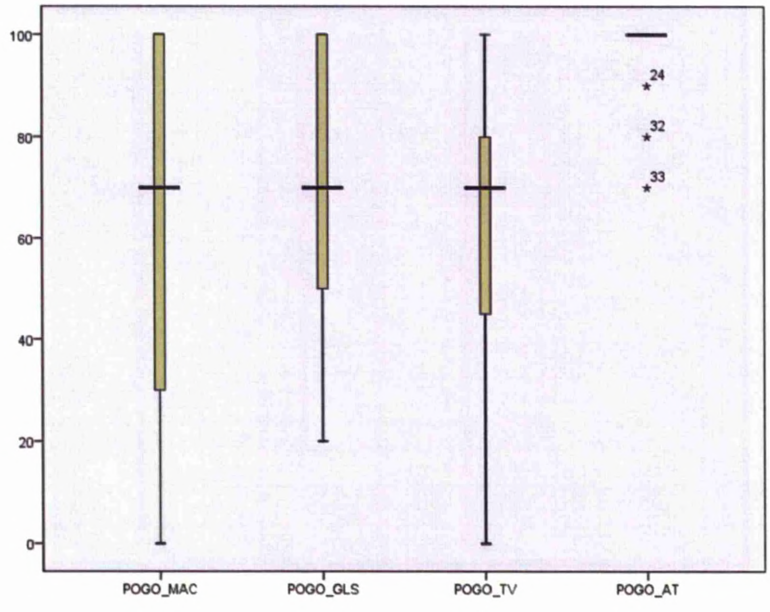

Figure 47 Boxplot of POGO scores for individual blades

The thick line represents the median score, vertical lines the range and box ends the upper and lower quartiles.

Using Macintosh as the "gold standard" initial analysis was targetted to the premise that POGO view would depend on the proximity of its blade tip to line IT and the analysis would develop on an ad hoc basis to deal with the other blades.

1. **Relationship between neck skin distance of blade tip and POGO scores.**

   Mac POGO = 105.97 – 22. 15 x neck skin distance (p=0.033)

   For Glidescope, Truview and Airtraq no significant correlation was present between POGO and neck skin distance.

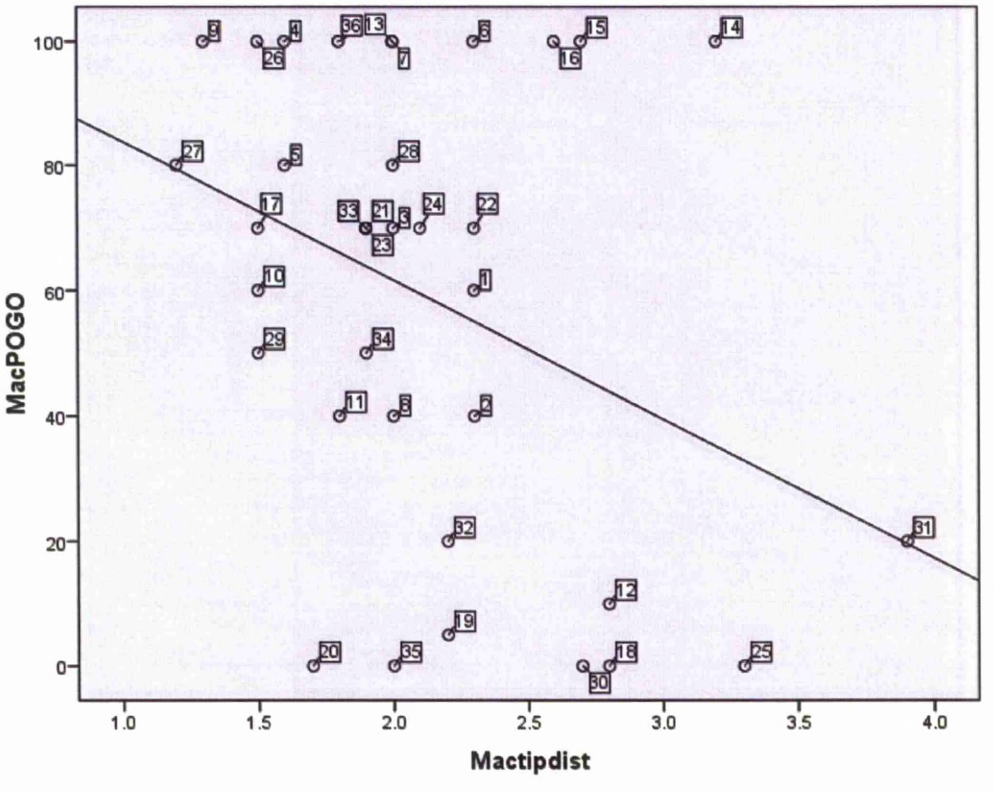

Figure 48 Scatter plot to show correlation between Macintosh POGO scores and blade tip distance from neck skin.

(Individual cases are labelled). Mactipdist is a measure of blade tip distance from neck skin (see text).

2. **Relationship between depth of insertion, percentage depth of insertion, IT distance and POGO**

For Macintosh there was only a significant correlation with depth of insertion:

POGO = 347.72 – 24.232 x DOI_Mac (p=0.002)

For Glidescope, Truview and Airtraq no correlation was present with DOI or PDOI.

There was no significant correlation between IT distance and POGO for any of the blades.

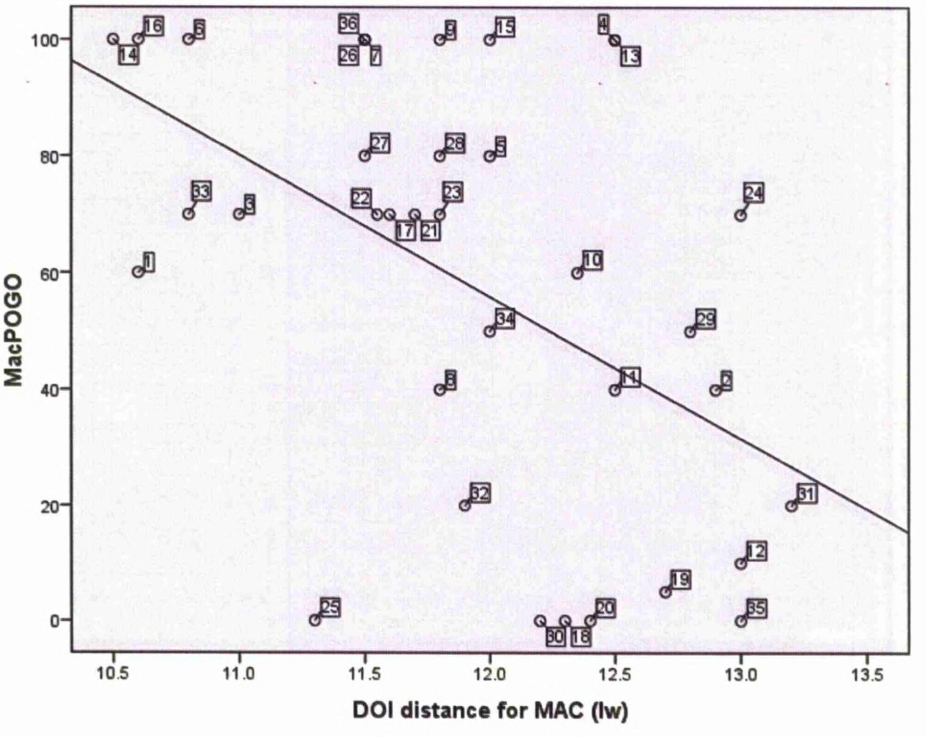

Figure 49 Scatter plot showing the correlation between Macintosh POGO and Depth of Insertion for Macintosh.

3. **Relationships between eyeline deviation angles TIL (comprising angles TIB plus BIL) for Macintosh and angles TEL for IDL versus POGO scores**

In the first place the significant correlations were:

Macintosh POGO= 98.6 – 4.8 *ang_ TIL (p = 0.000)

Glidescope POGO= 82.167 - 1.546 *ang_TEL (P= 0.017)

Truview and Airtraq eyeline deviation angles had no correlation with POGO scores.

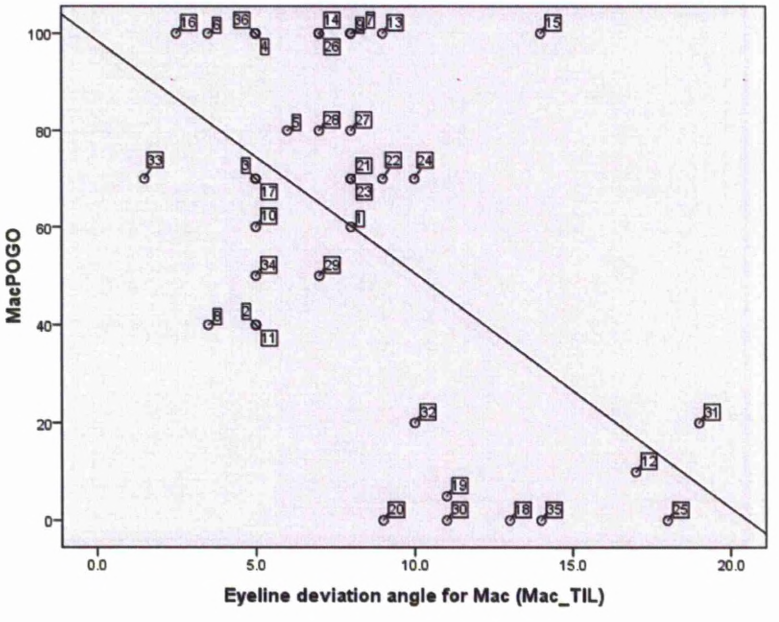

Figure 50 Scatter plots showing correlations between Macintosh POGO score and Eyeline deviation angle TIL

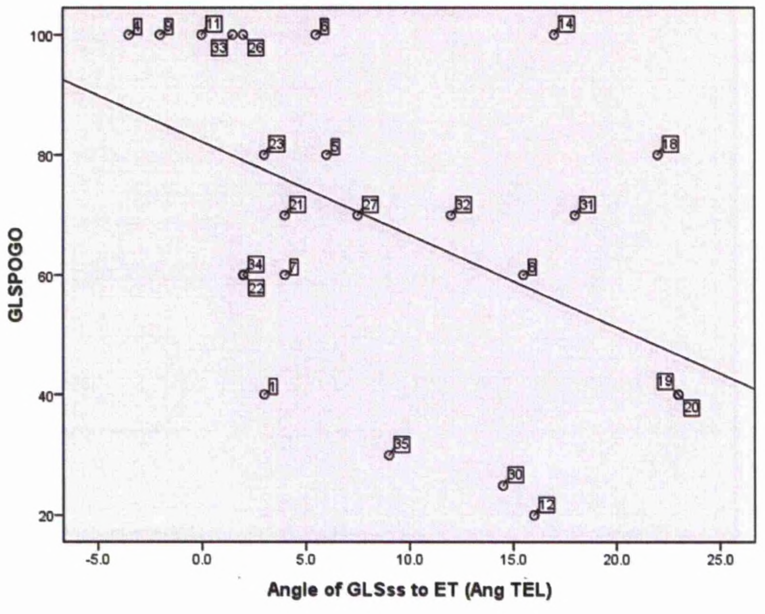

Figure 51 Scatter plots showing correlations between Glidescope POGO scores and Eyeline deviation angle TEL.

As illustrated in figure 44, eyeline deviation angle TIL consists of angle TIB plus angle BIL. Angle TIB represents effectively how much the blade is pushed backwards relative to IT whereas angle BIL represents eye line displacement due to the curve of the blade. Only angle TIB was correlated to POGO (p=0.000).

A stepwise regression model for Macintosh POGO and the variables so far gave:

Mac POGO = 289.959 – 7.347 x ang_TIB – 13.833 x IT (p=0.000)

Figure 52 is a 3-D scatter graph demonstrating this relationship.

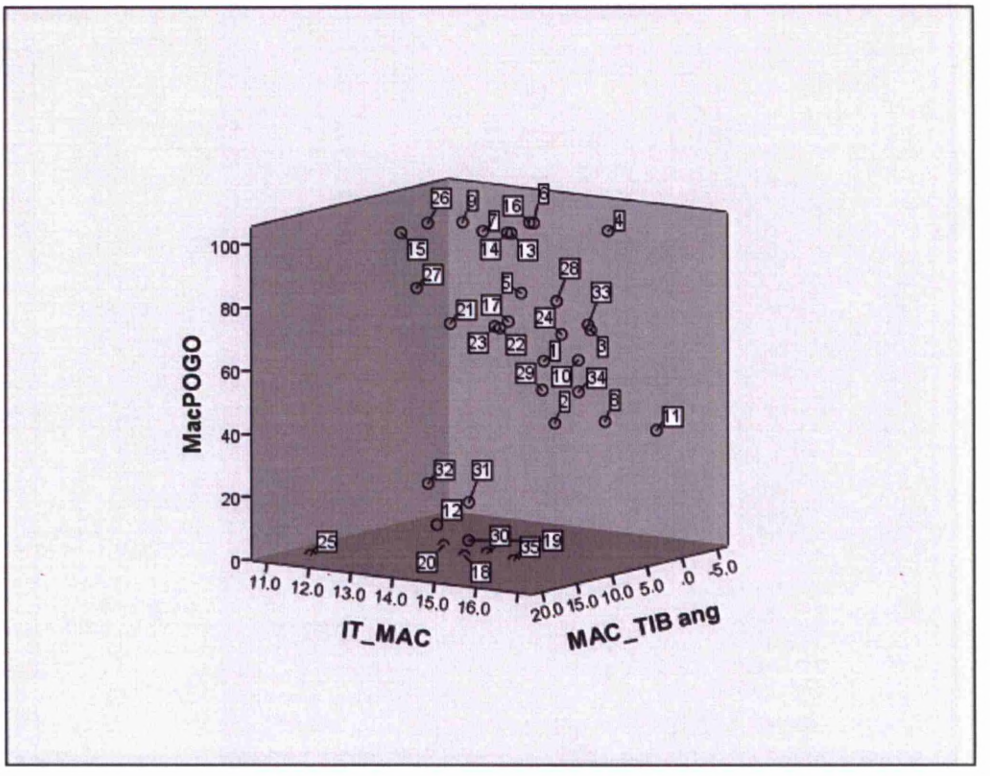

Figure 52 3D scatter graph representing Mac POGO on Y axis, IT for Mac on X axis and Angle TIB on Z axis.

The results so far are summarized in Table 5.

Variables	Mac	Gls	Trv	Art
Neck skin distance	p=0.033 POGO=106 –22.2*neck distance	Ns	ns	ns
Depth of insertion, DOI	p=0.002 POGO=348 – 24.2*DOI_Mac	Ns	ns	ns
Percentage depth of insertion, PDOI (%Iw/IT)	ns	Ns	ns	ns
Incisor point to tracheal point distance, IT	ns	Ns	ns	ns
Ang TIL /TEL	p=0.000 POGO =99 – 4.8 *ang TIL	p=0.017 POGO=82 -1.5*ang_TEL	ns	ns
Ang TIB	p=0.000 POGO=84.74 – 5.17*ang_TIB	NA	NA	NA
Ang BIL	ns	NA	NA	NA
Ang ETL	NA	Ns	ns	ns
Stepwise regression	p=0.000 POGO=290 – 7.3*ang_TIB–13.8 *IT	p=0.017 POGO=82 –1.5*ang_TEL	ns	ns

Table 5 Correlation of variables with POGO scores with individual blade given as p values and regression equations.

4. Relationship between area measures and POGO

On the basis of what was described in the Methods, the next stage was to compare POGO values with areas, green, red, black and blue. Distribution of areas was as shown in figure 53.

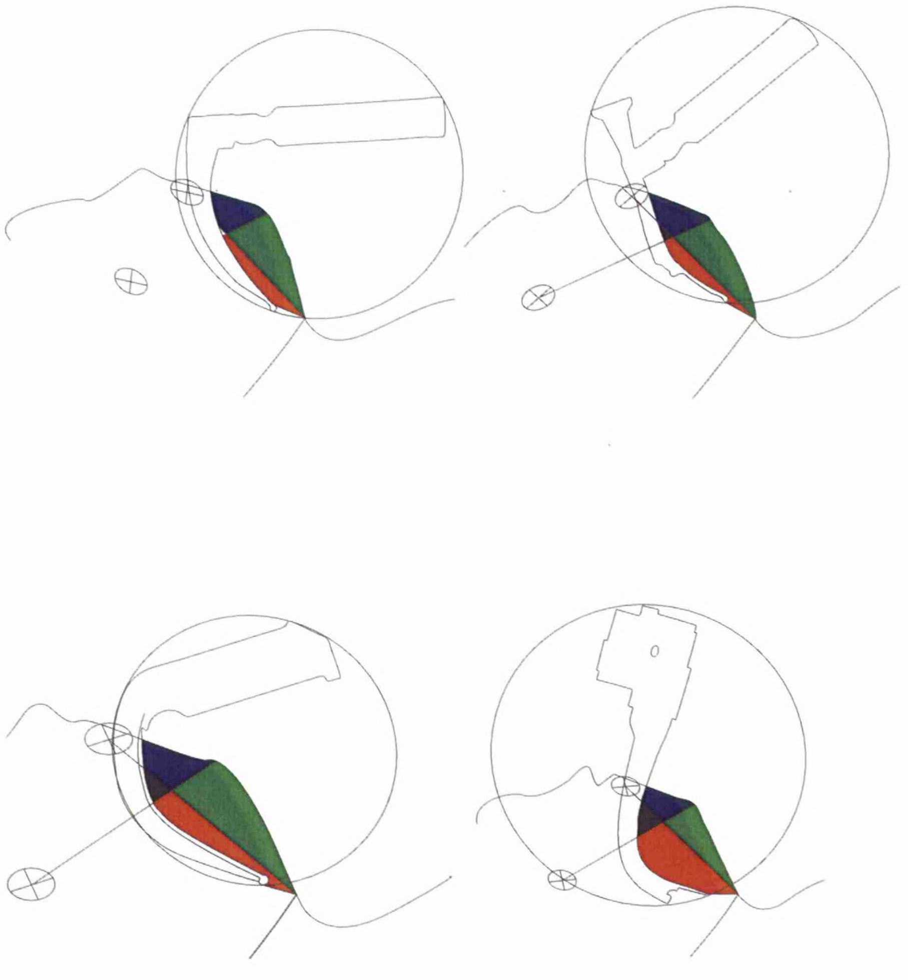

Figure 53 Areas of interest in front of the each blade.

Areas are divided up by the lines IT (incisors to anterior airway) and JS. JS extends from point J forwards so as to intersect IT 2/3 up from T. The Green area is the antero-inferior zone, Red is behind IT and black area is in front of the blade and behind IT. Blue area is between IT and neck skin.

Following table gives the descriptive values for the areas for each device.

Green	Mean	SD		**Red**	Mean	SD	
Mac_Green	20.766	3.127		Mac_Red	8.821	5.639	
Gls_Green	17.573	2.613		Gls_Red	11.859	7.155	
Trv_Green	19.307	3.498		Trv_Red	9.404	5.120	
Art_Green	15.129	2.312		Art_Red	19.340	6.911	
Green&Red	Mean	SD		**Blue**	Mean	SD	
Mac_GR	29.335	5.535		Mac_blue	9.167	2.611	
Gls_GR	29.432	6.854		Gls_blue	8.834	2.078	
Trv_GR	28.711	5.872		Trv_blue	10.899	3.170	
Art_GR	34.469	5.768		Art_blue	6.852	1.827	
Black	Mean	SD					
Mac_Black	0.321	0.405					
Gls_Black	1.858	1.006					
Trv_Black	0.788	0.645					
Art_Black	1.983	0.963					

Table 6 Mean values and standard deviation for all the areas for each blade.

Correlation of POGO scores with area measures for all the blades gave following results (Table 7). For Truview POGO and Airtraq POGO none of the areas were correlated.

Area	**Mac**	**Gls**	**Trv**	**Art**
Green	ns	ns	ns	ns
Red	p=0.000 POGO = 94.1– 3.9 *Mac_Red	p=0.046 POGO = 86.8 – 1.5 *Gls_Red	ns	ns
Green&Red	p=0.000 POGO = 168 – 3.7 *Mac_GR	p=0.023 POGO = 121 – 1.768 *Gls_GR	ns	ns
Black	p=0.01 POGO=74.3–47.6 *Mac_black	Ns	ns	ns
Blue	ns	Ns	ns	ns
Stepwise regression	p=0.000 POGO = 92.2 – 3.9 *Mac_Red	p=0.023 POGO = 121 – 1.768 *Gls_GR	ns	ns

Table 7 Correlations of POGO scores for each blade with individual areas.

5. Relationship between pre-operative patient measurements and POGO

Pre-operative measurements were initially correlated individually to POGO for each blade and then stepwise regression was done to see the most significant factor (Table 8).

Variables	Mac	Gls	Trv	Art
Height	ns	ns	ns	ns
Weight	p=0.005 POGO = 132 -0.96 *Wt	p=0.039 POGO=114 – 0.59 *Wt	ns	ns
BMI	p=0.011 POGO = 141–3.02 *BMI	p=0.016 POGO = 132-2.3 *BMI	p=0.042 POGO =133–2.6 *BMI	ns
ArmSpan	p=0.028 POGO = 320 – 1.5 *armspan	ns	Ns	ns
Inter-incisor distance IID	ns	ns	p=0.040 POGO = -43.6+22.1 *IID	ns
Inter-condylar Distance ICD	p=0.005 POGO = 255.81– 14.321 *ICD	p=0.057	ns	ns
ExtCond-to - IntSym	ns	ns	ns	ns
Neck Ext	ns	ns	ns	ns
Stepwise Regression	p=0.002 POGO = 224.81– 17.935 ICD + 17.398 IID	p=0.016 POGO = 131.69-2.318 *BMI	p=0.000 POGO= -19.7 +34.7*IID -1.15*Wt	ns

Table 8 Correlation of individual pre-operative factors with POGO scores for each blade as p values with regression equation.

ExtCond-to-IntSym denotes distance between the posterior mandibular condyle and the internal midpoint of the symphysis menti.

The model obtained for Macintosh was: Mac_POGO = 224.81- 17.935 ICD + 17.398 IID (p=0.002). This is represented in a 3-D graph in figure 54.

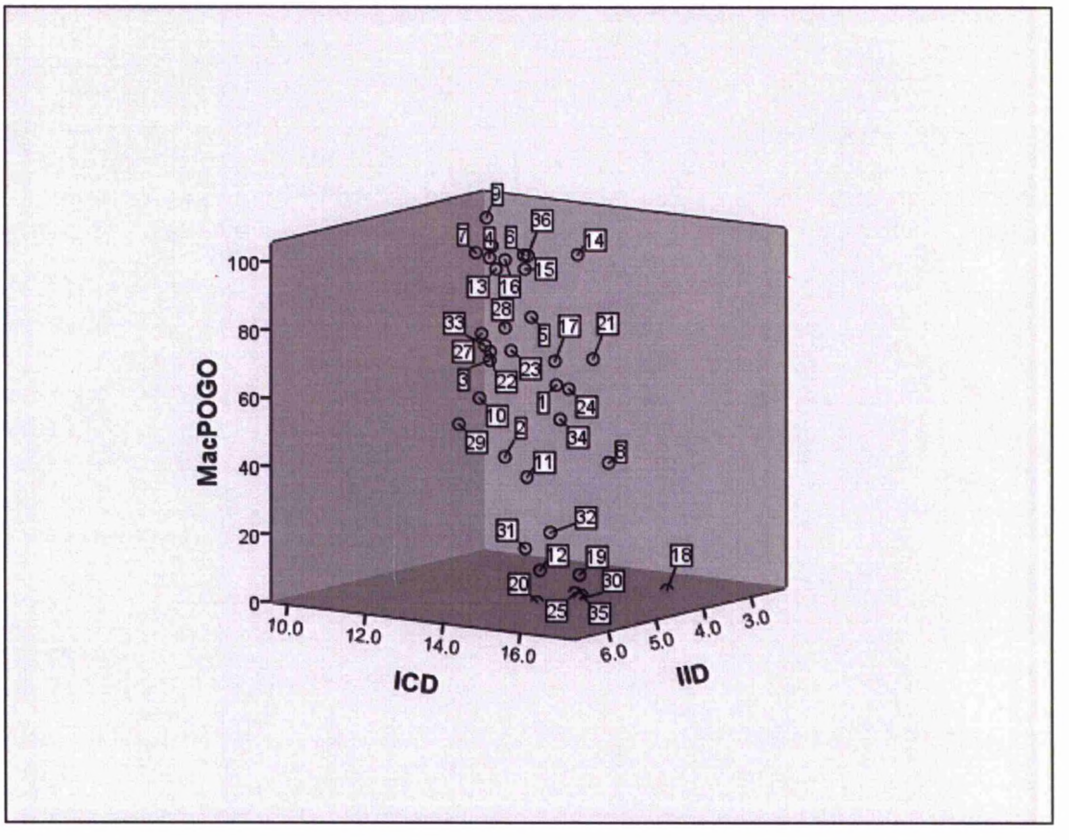

Figure 54 3-D Scatter dot of Macintosh POGO (Y axis), Inter-condylar distance (X axis) and Inter-incisor distance (Z axis).

Individual case numbers are displayed in boxes.

For Airtraq POGO stepwise regression didn't reveal any significant variable

6. Relationship between JIST lines and POGO

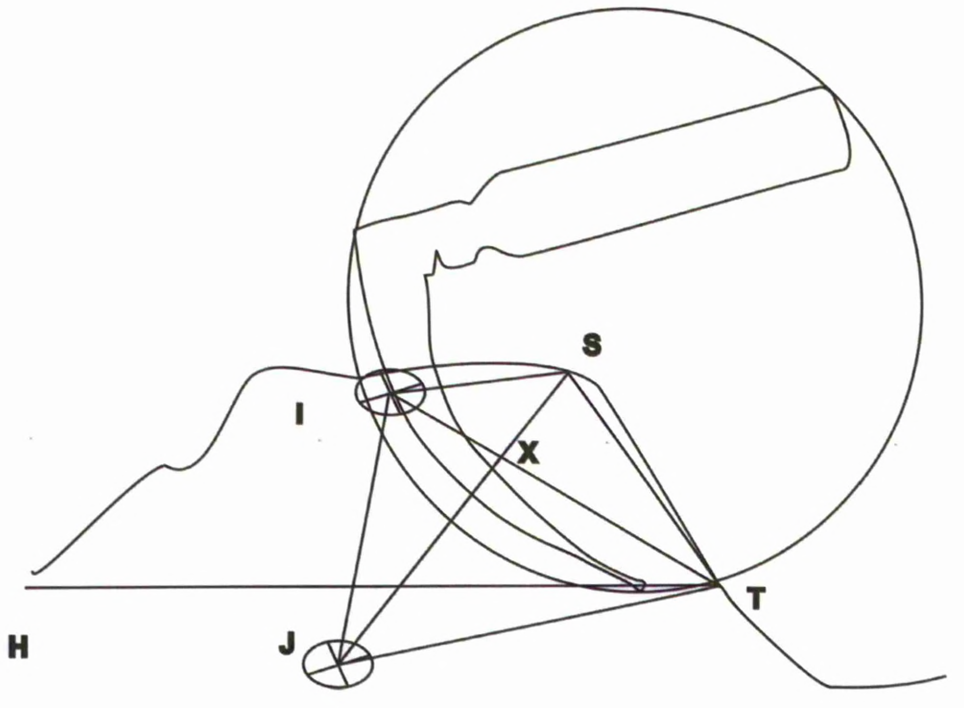

Figure 55 Macintosh laryngoscopy with reference points JIST and X calculated as 1/3rd distance up from T point.

Line HT is added as a horizontal to IT.

Table 9 shows correlation of individual lines with POGO scores.

Lines	**Mac**	**Gls**	**Trv**	**Art**
JI	0.005 POGO =194.99 – 13.219 *JI	0.036 POGO = 151.62– 8.693 *JI	ns	ns
JT	0.024 POGO = 174.556 – 7.936*JT	ns	ns	ns
ST	ns	ns	ns	ns
JS	0.007 POGO = 195.47 – 9.98 *JS	ns	ns	ns
IS	ns	ns	ns	ns
IX	ns	ns	ns	ns
SX	ns	ns	ns	ns
Stepwise regression	0.005 POGO = 194.99 – 13.219 *JI	0.036 POGO = 151.62– 8.693 *JI	ns	ns

Table 9 Correlation of individual lines with POGO for each blade displayed as p values with regression equations

Because of the apparent relationship between lines JI, JS and JT with Macintosh POGO, this was further explored in 3D scatter plot graph.

Lines JI, JS and JT were related to each other as follows:

JS= 2.296 + 1.106 *JI (p=0.000)

JS= 1.94 +0.0806 *JT (p=0.000)

JT= 6.1 + 0.82 *JI (p-0.000)

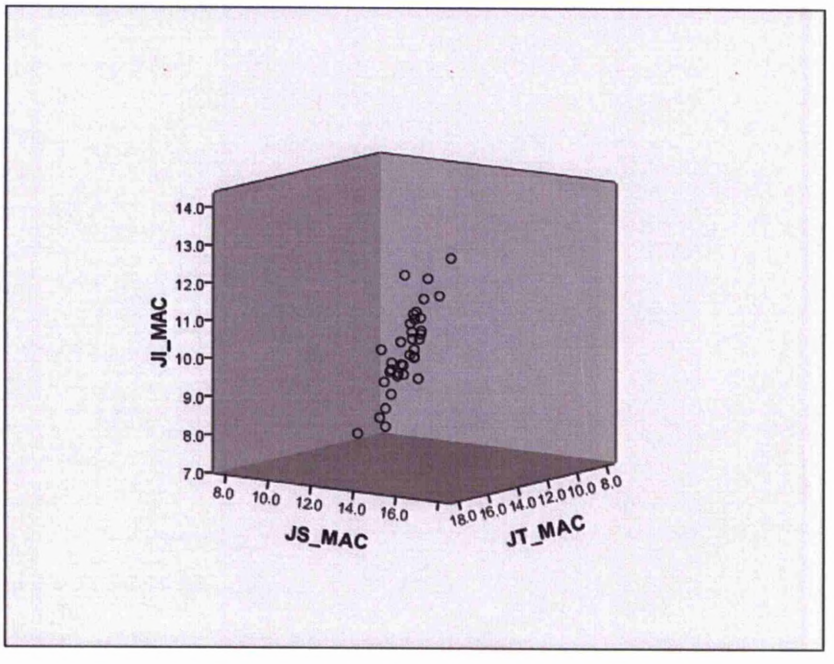

Figure 56 3-D Scatter Dot graph to explore relationship between JI, JS and JT lines. JI represented on X axis, JS on Y axis and JT on Z axis.

7. Relationship between JIST angular measurements and POGO

Angles were measured from the above line diagram (figure 56) and correlated individually to POGO for each blade. Angle IJT was significantly correlated to POGO for both Macintosh and Glidescope (figure 57). Table 10 shows correlations for individual angles with POGO for each blade.

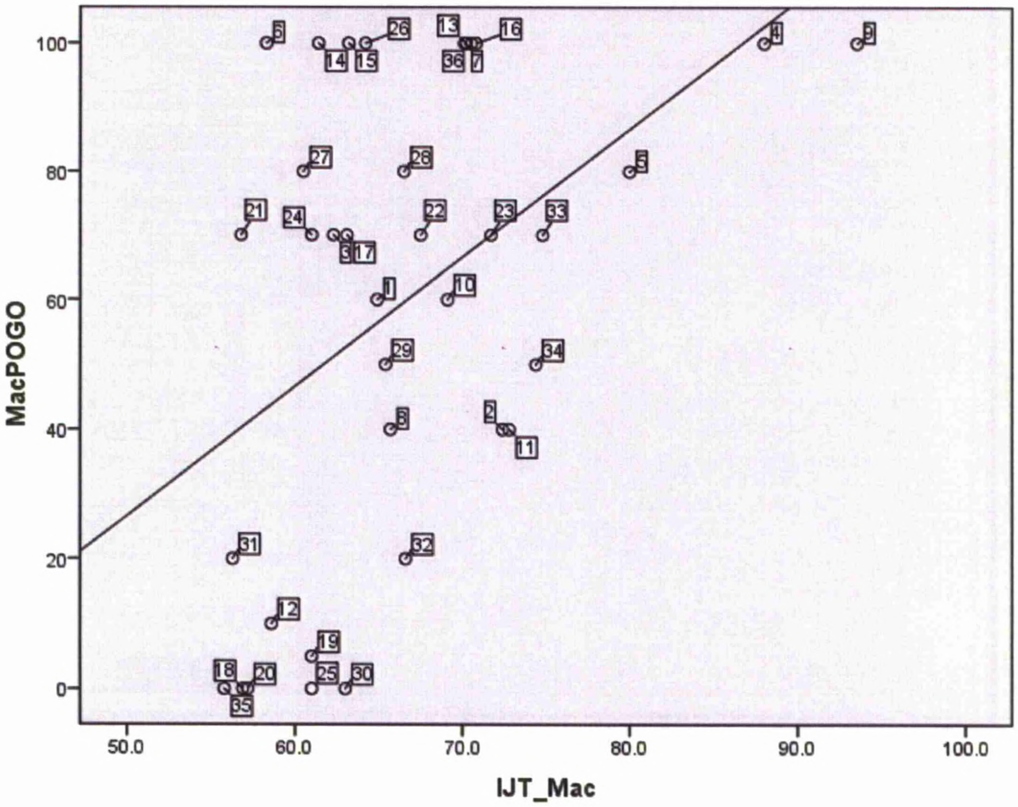

Figure 57 Scatter plots showing correlations between POGO scores and IJT angle for Macintosh.

Angle	Mac	GLS	TRV	ART
HTI	0.010 POGO = -22.1 + 2.5 *HTI_Mac	ns	ns	ns
IST	ns	ns	ns	ns
ITS	ns	ns	ns	ns
JXT	ns	ns	ns	ns
SXT	ns	ns	ns	ns
JIT	0.044 POGO = 181 – 1.7 *JIT_Mac	ns	ns	ns
TIS	ns	ns	ns	ns
IJT	0.004 POGO= -73.4 + 2 *IJT_Mac	0.030 POGO = -5.64 + 1.1 *IJT_Gls	ns	ns
IJS	0.010 POGO = -43 + 3.8 *IJS_Mac	ns	ns	ns
SJT	0.013 POGO = -51.5 + 2.8*SJT_Mac	ns	ns	ns
ITJ	ns	0.024 POGO = 161 – 2.4 *ITJ_Gls	ns	ns
Stepwise regression	(Only IJT in model)	(Only ITJ in model)		

Table 10 Correlation of individual angles with POGO for each blade displayed as p values with regression equations.

8. Relationship of F value and POGO

The area available for accommodating IRV is described by a mathematical formula (60):

F = 100 x XT/IT x XS/JS x sin (Beta), Where Beta is angle SXT.

According to Charters, clinical experience has shown that intubation becomes difficult when F value is below 15 The F value was calculated in this clinical study for each blade using above formula (note that here S represents a point on the skin, not on the internal surface of the ramus). This was then individually correlated to POGO for each blade.

Mac POGO = -56.19 + 6.283*F (p=0.008) (Small F means small POGO)

This is in line with the original concept of F value. For Glidescope, Truview and Airtraq POGO, F values were not significantly correlated.

Section B

This section describes differences between blade pairs. These are described relative to: POGO; neck skin distance from blade tip; depth of insertion; percentage depth of insertion; IT distance; eyeline deviation angle; JIST lines and angles and finally F value.

1. **Comparison of POGO for blade pairs**

Compared with Macintosh, Glidescope and Airtraq had better POGO scores. For the IDL pairings, the only difference was Airtraq had better scores than Truview.

2. **Comparison of neck skin distance for blade pairs**

There were no differences either in comparison to Macintosh or IDL blade pairings.

3. Comparison of Depth of Insertion for blade pairs

The only difference was between Macintosh and Truview where Macintosh had greater depth of insertion.

4. Comparison of Percentage Depth of Insertion for blade pairs

Here Macintosh had greater percentage depth of insertion than Truview but smaller than Airtraq. For the IDL pairings only Glidescope and Truview were different, with Glidescope showing greater percentage depth of insertion.

5. Comparison of IT for blade pairs

IT distance was smaller for Airtraq compared with Macintosh and both Glidescope and Truview.

6. Comparison of angle TEL between IDLs

Here angle TEL was larger for Glidescope compared to Truview.

7. Comparison of IE and EIT angles versus ET and IET angles between IDLs

Airtraq had IE distance and angle EIT greater than both Glidescope and Truview, whereas distance ET and angle IET were smaller for Airtraq than both Glisedscope and Truview.

8. Comparisons between blade pairs for individual area measures.

For the Black area measures Macintosh was smaller than all the IDLs. Whereas for the IDL pairings, both Airtraq and Glidescope had larger Black areas than Truview.

For the Blue areas Truview had larger Blue area than Macintosh; however Macintosh had larger Blue area than Airtraq. In the IDL pairings Truview Blue area was again larger than both Airtraq and Glidescope whereas Glidescope had larger Blue area than Airtraq.

For the Green areas Macintosh had larger Green area than all the IDLs. In the IDL pairings Glidescope and Truview had larger Green area than Airtraq. For the red areas Macintosh was smaller than both Glidescope and Airtraq and in the IDL pairings, Airtraq was bigger than both Glidescope and Truview. When the Green and Red areas were considered in combination, only Airtraq was bigger than Macintosh and in the IDL pairings Airtraq again was bigger than both Glidescope and Truview. The combined GR area comparisons are highlighted in figures 59-61 where Macintosh is compared with each IDL in turn and contrasted in each figure with a line of equality.

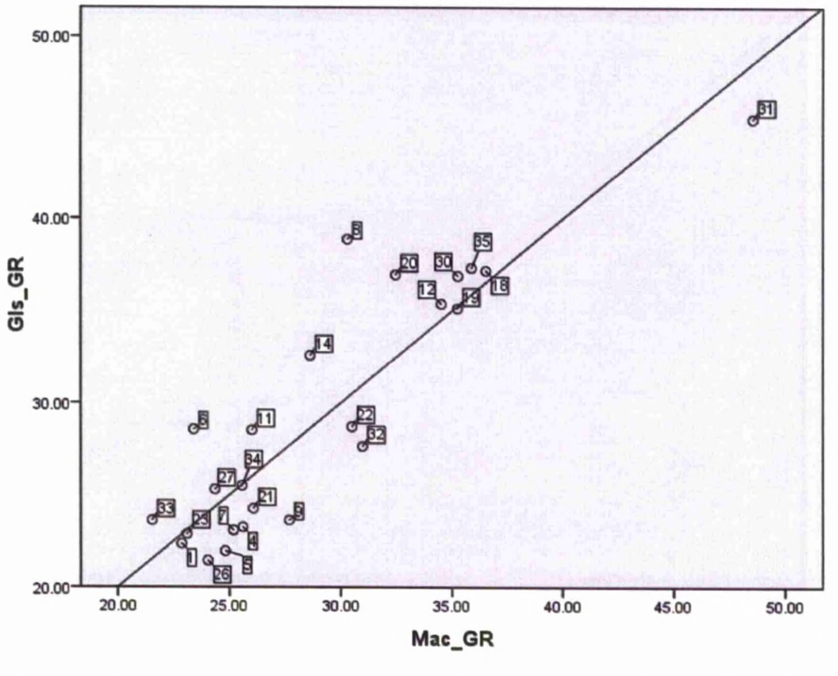

Figure 58 Scatter plot of GR areas for Glidescope and Macintosh with line of equality.

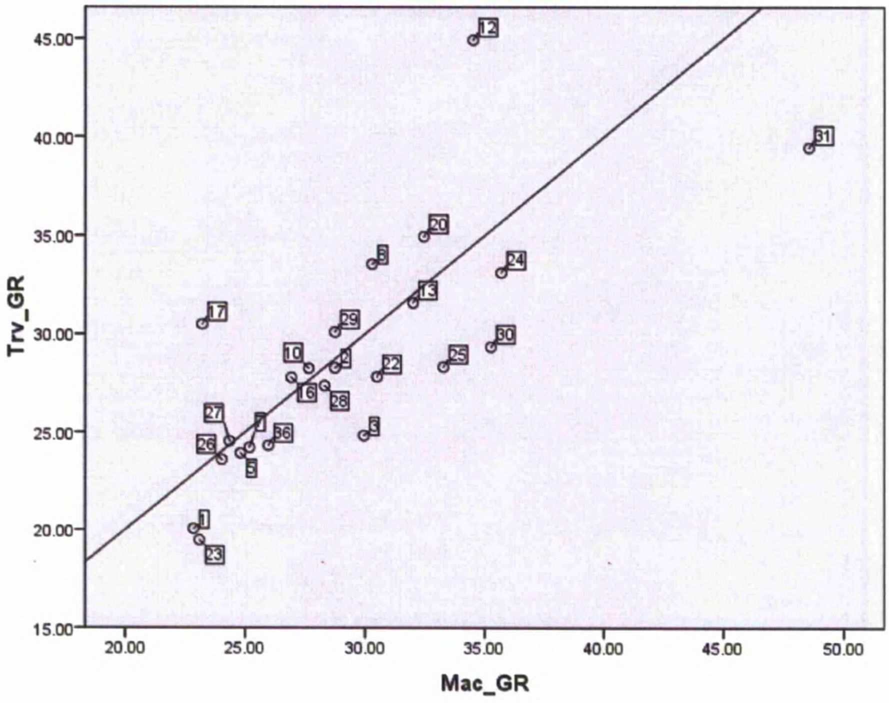

Figure 59 Scatter plot of GR areas for Truview and Macintosh with line of equality.

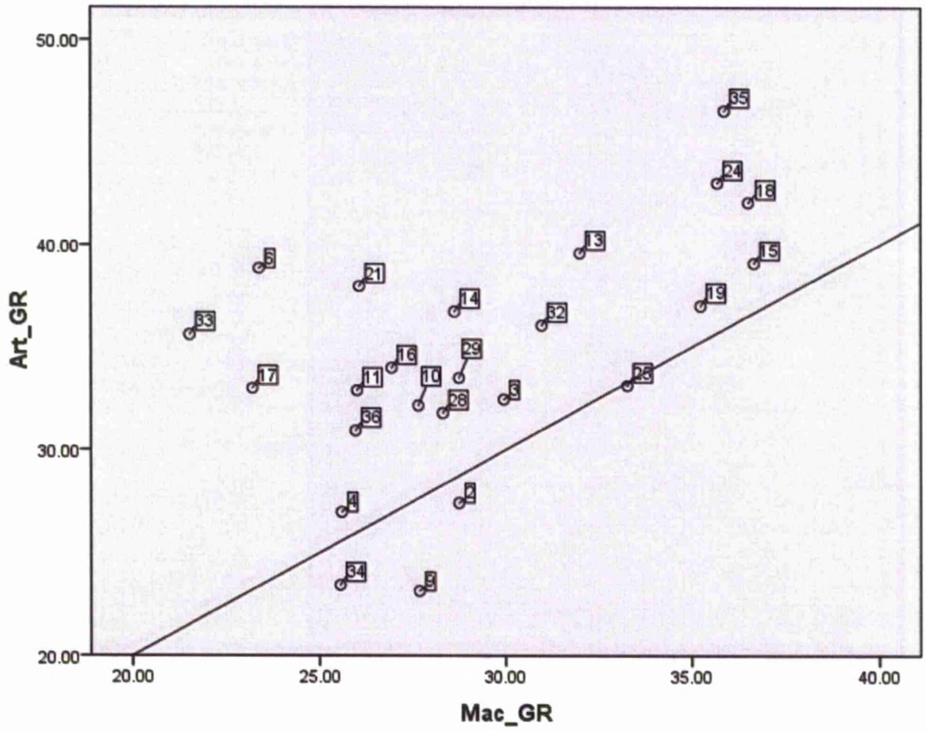

Figure 60 Scatter plot of GR areas for Airtraq and Macintosh with line of equality.

9. Comparison between blade pairs for JIST lines

Lines JI and JS were significantly bigger for Macintosh as compared with Glidescope and Airtraq. Similarly in the IDL pairings, lines JI and JS were smaller for Truview as compared with Glidescope and Airtraq. Line JT was smaller for Macintosh compared with Truview but larger for Macintosh compared with Airtraq. In the IDL pairings Truview was larger than both Glidescope and Airtraq. Line SX was bigger for Macintosh compared with Airtraq whereas for IDL pairings, both Glidescope and Truview were bigger than Airtraq.

10. Comparison between blade pairs for JIST angles

Angles IJT and IJS were bigger with Glidescope than Macintosh whereas in IDL pairings Glidescope was bigger than Airtraq. For Angle HTI Macintosh was bigger than Truview and in the IDL pairings, Airtraq was bigger than Truview. Angle FIJ only showed differences between Macintosh and Airtraq (Macintosh was the larger). There were no differences for any JIT pairs. For angle JXT Macintosh was smaller than Glidescope and Airtraq and in the IDL pairings Glidescope was bigger than Truview.

11. Comparison of 'F' values for blade pairs

Airtraq had a smaller F value compared with Macintosh and also compared with Truview.

Variables	Comparisons with Macintosh			Comparisons between IDLs		
	MvG	**MvT**	**MvA**	**GvT**	**GvA**	**TvA**
n=	24	23	24	12	12	11
POGO	0.012(G)	ns	0.000(A)	ns	ns	0.009(A)
Neck skin distance	ns	ns	ns	ns	ns	ns
DOI (depth of insertion)	ns	0.041(M)	ns	ns	ns	ns
%DOI	ns	0.048(M)	0.028(A)	0.044(G)	ns	ns
IT	ns	ns	0.000(M)	ns	0.017(G)	0.003(T)
TEL	NA	NA	NA	0.02(G)	ns	ns
IE	NA	NA	NA	ns	0.000(A)	0.000(A)
EIT	NA	NA	NA	ns	0.001(A)	0.004(A)
ET	NA	NA	NA	ns	0.001(G)	0.000(T)
IET	NA	NA	NA	ns	0.000(G)	0.000(T)
black area	0.000(G)	0.000(T)	0.000(A)	0.005(G)	ns	0.005(A)
blue area	ns	0.037(T)	0.001(M)	0.044(T)	0.003(G)	0.002(T)
green area	0.001(M)	0.048(M)	0.000(M)	ns	0.002(G)	0.000(T)
red area	0.018(G)	ns	0.000(A)	ns	0.000(A)	0.000(A)
GR_area (green + red)	ns	ns	0.000(A)	ns	0.002(A)	0.000(A)

Table 11 Paired comparisons between Macintosh and each IDL; then IDL pairs with p values and larger value in brackets

Variables	**Comparisons with Macintosh**			**Comparisons between IDLs**		
	MvG	**MvT**	**MvA**	**GvT**	**GvA**	**TvA**
n=	24	23	24	12	12	11
JI	0.000(M)	ns	0.000(M)	0.023(T)	ns	0.006(T)
JS	0.000(M)	ns	0.000(M)	0.001(T)	ns	0.000(T)
JT	ns	0.036(T)	0.021(M)	0.031(T)	ns	0.002(T)
SX	ns	ns	0.000(M)	ns	0.048(G)	0.000(T)
IJT	0.013(G)	ns	ns	ns	0.030(G)	ns
IJS	0.000(G)	ns	ns	ns	0.026(G)	ns
HTI	ns	0.046(M)	ns	ns	ns	0.007(A)
FIJ	ns	ns	0.023(M)	ns	ns	ns
JIT	ns	ns	ns	ns	ns	ns
JXT	0.005(G)	ns	0.006(A)	0.000(G)	ns	ns
F	ns	ns	0.001(M)	ns	ns	0.033(T)
GR_ area/F ratio	ns	ns	0.000 (A)	ns	0.000(A)	0.003(A)

Table 12 Continuation of the paired comparisons (Macintosh versus each IDL, then IDL pairs) in table 11

Section C. Relationships of interest

a. Relationship for IT and eye line deviation angles with pre-operative factors

In section A, Table 5, it was shown that

Mac POGO = 290 -7.3 x ang_TIB – 13.8 x IT (p=0.000)

Mac POGO = 84.74 – 5.17 x ang_TIB (p=0.000)

Gls POGO = 82 –1.5*ang_TEL (p=0.017)

Stepwise regression of Macintosh IT and angle TIB with all preoperative factors resulted in the following models:

Mac_IT = 4.165 +0.5 x Ht + 0.038 x NeckExt (p=0.01)

Ang_TIB = 4.224 + 2.97 x BMI – 0.181 x Neck Ext (p= 0.000)

Stepwise regression of Glidescope IT and angle TEL for all preoperative factors gave model:

GLS_Ang_TEL = -49.76 + 3.46 x ExtCond-to-IntSym + 0.194 x Wt (p= 0.000)

Glidescope IT had no relation with pre-operative factors (neither did Truview or Airtraq)

b. Relationship of individual GR area with pre-operative measurements

Table 13 shows individual GR measures against each of the pre-operative factors and the summarizing stepwise regression. We chose to further correlate each blade GR area with Inter-condylar (ICD) distance and distance between J point and internal midpoint of mandibular symphysis (ExtCond-to-IntSym) in stepwise regression (as measures of mandibular size).

Mac_GR = -22.85 + 1.423 x ICD + 2.662 x ExtCond-to-IntSym(p=0.000)

Gls_GR = -38.96 + 2.808 x ICD + 2.417 x ExtCond-to-IntSym(p=0.000)

$$Trv\_GR = -33.98 + 2.525 \times ICD + 2.253 \times ExtCond\text{-}to\text{-}IntSym (p=0.002)$$

$$Art\_GR = -23.72 + 2.241 \times ICD + 2.2174 \times ExtCond\text{-}to\text{-}IntSym\ (p=0.000)$$

Variables	**Mac_GR**	**Gls-GR**	**Trv_GR**	**Art_GR**
Height	p=0.019 GR=-13.113 +0.255*Ht	p=0.005 GR= -39.983 +0.415*Ht	p=0.027 GR= -33.013 +0.415*Ht	p=0.001 GR= -34.348 +0.414*Ht
Weight	p=0.000 GR= 13.469 +0.209*Wt	p=0.000 GR= 7.6+0.285*Wt	p=0.000 GR=10.389 +0.249*Wt	p=0.000 GR= 16.197 +0.239*Wt
BMI	p=0.000 GR= 11.961 +0.641*BMI	p=0.000 GR= 6.720 +0.839*BMI	p=0.002 GR= 8.792 +0.753*BMI	p=0.020 GR= 18.43 +0.582*BMI
ArmSpan	p=0.016 GR= -14.267 +0.26*armspan	p=0.006 GR= -35.801 +0.39*armspan	p=0.001 GR= -62.99+0.551*armspan	p=0.002 GR= -32.681+0.398*armspan
IID	ns	ns	0.027	Ns
ICD	p=0.001 GR= -5.917 +2.565*ICD	p=0.000 GR= -22.958 +3.822*ICD	p=0.003 GR= -17.184 +3.35*ICD	p=0.000 GR= -8.229 +3.093*ICD
ExtCond-to-IntSym	p=0.000 GR= -12.482 +3.364*ExtCond-to-IntSym	p=0.000 GR=-24.616 +4.037*ExtCond-to-IntSym	p=0.006 GR= -11.648 +3.226*ExtCond-to-IntSym	p=0.002 GR= -9.716 + 3.522 *ExtCond-to-IntSym
Stepwise Regression	p=0.000 GR = -8.75+0.143*wt +2.174*ExtCond-to-IntSym	p=0.000 GR = -19.32 +0.21*wt + 2.57* ExtCond-to-IntSym	p=0.001 GR = 10.38 +0.25*wt	p=0.000 GR = -7.006 + 0.18*wt + 2.21 ExtCond-to-IntSym

Table 13 Relationship between pre-operative patient measurements and GR area (as a measure of backwards displacement) for each blade as p values

c. Relationship of individual F with pre-operative measurements

F is a measure of the space available into which tongue IRV gets accommodated during Macintosh laryngoscopy and there are equivalent F values for the other 3 blades.

Stepwise regression against pre-operative factors gave the following models:

$F\_Mac = 30.091 - 1.077 \times ICD + 0.077 \times NeckExt$ ($p=0.000$)

$F\_Gls = 68.788 - 0.223 \times Ht - 1.088 \times ExtCond\text{-}to\text{-}IntSym$ ($p=0.000$)

F_Trv gave no model

$F\_Art = 46.2 - 2.147 \times ICD$ ($p=0.000$)

d. Relationship between GR area and F value for individual blade

$GR\_Mac = 47.013 - 0.964 \times F\_Mac$ ($p=0.008$)

$GR\_Gls = 48.026 - 1.046 \times F\_Gls$ ($p=0.009$)

$GR\_Art = 54.029 - 1.182 \times F\_Art$ ($p=0.000$)

There was no relation between GR area for Truview and its F value.

Thus GR area (IRV) was well matched to F value (space available to accommodate IRV) for Macintosh, Glidescope and Airtraq but not for Truview.

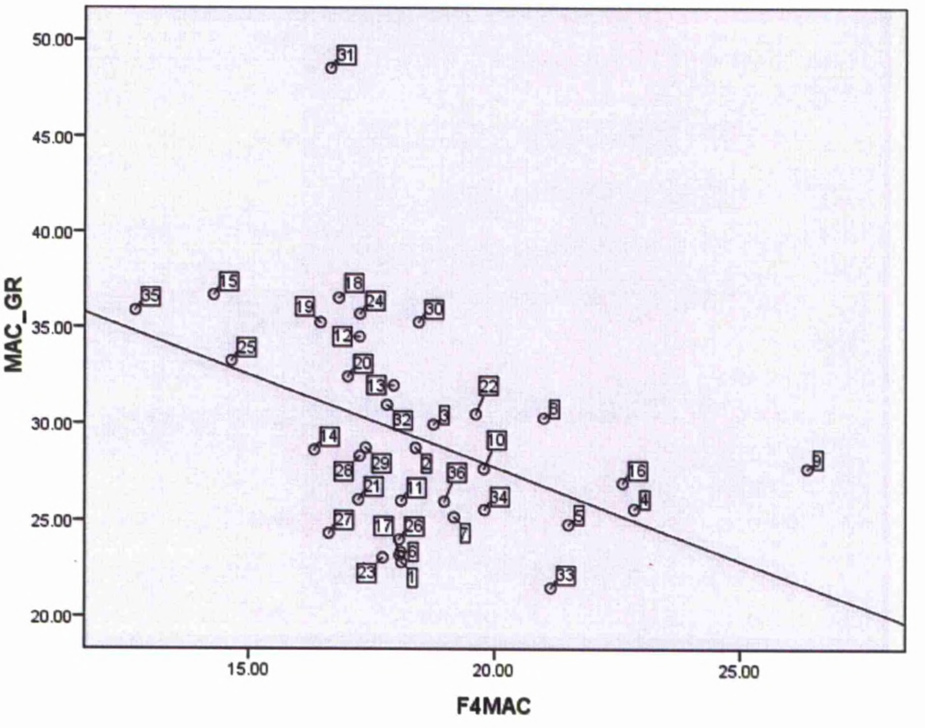

Figure 61 Scatter plot of Macintosh GR area versus F value for Macintosh (F4MAC)

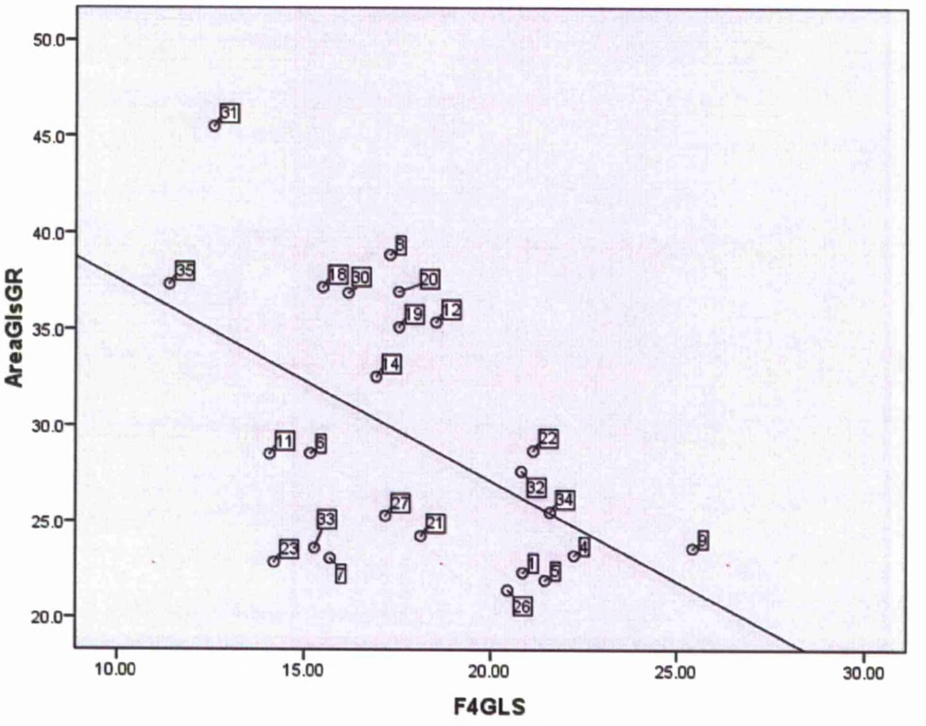

Figure 62 Scatter plot of Glidescope GR area versus F value for Glidescope

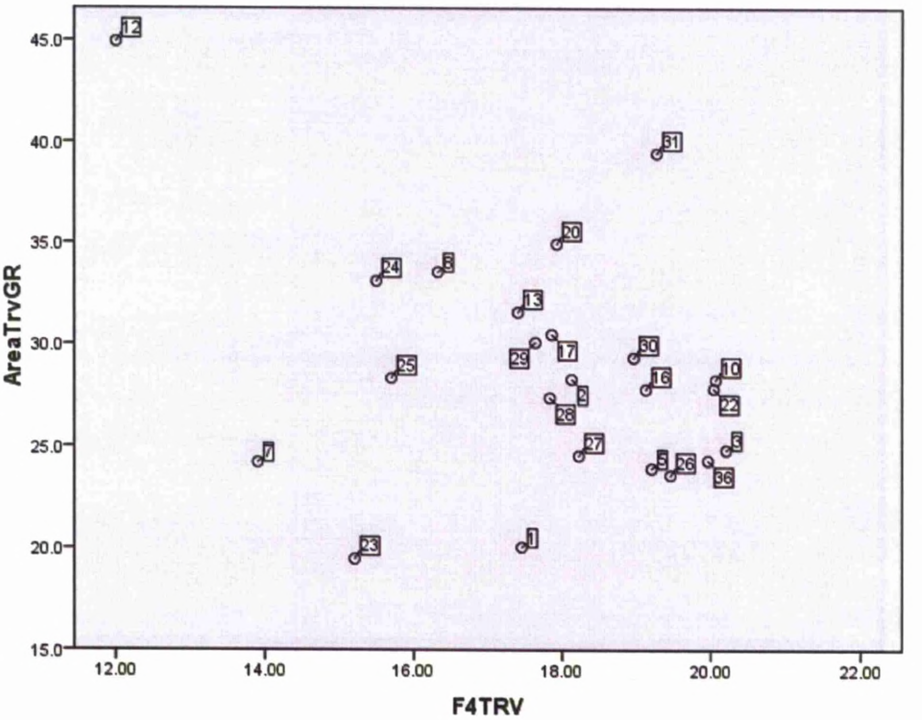

Figure 63 Scatter plot of Truview GR area versus F value for Truview

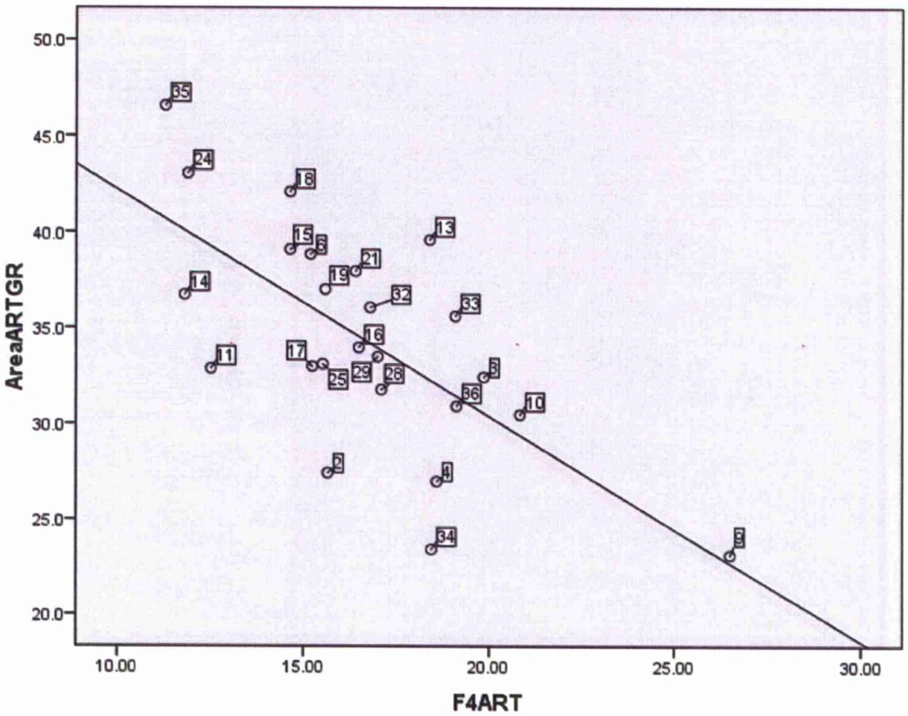

Figure 64 Scatter plot of Airtraq GR area versus F value for Airtraq

e. Relationship between POGO and ratio GR area / F value for individual blades

GR area represents inevitable residual volume and F represents the space available to accommodate IRV. Ratio of the two represents how well they are matched. The effect of this match or mismatch on POGO was as follows-

For Macintosh POGO = 132.444 – 44.562 x GR/F_Mac (p=0.000)

There was no correlation between POGO for other blades and GR/F ratio. However with Glidescope when outlier case 31 was taken off from analysis, POGO showed a model for GR/F ratio.GLS POGO = 102.195 – 19.888 x GR/F_GLS (p=0.044)

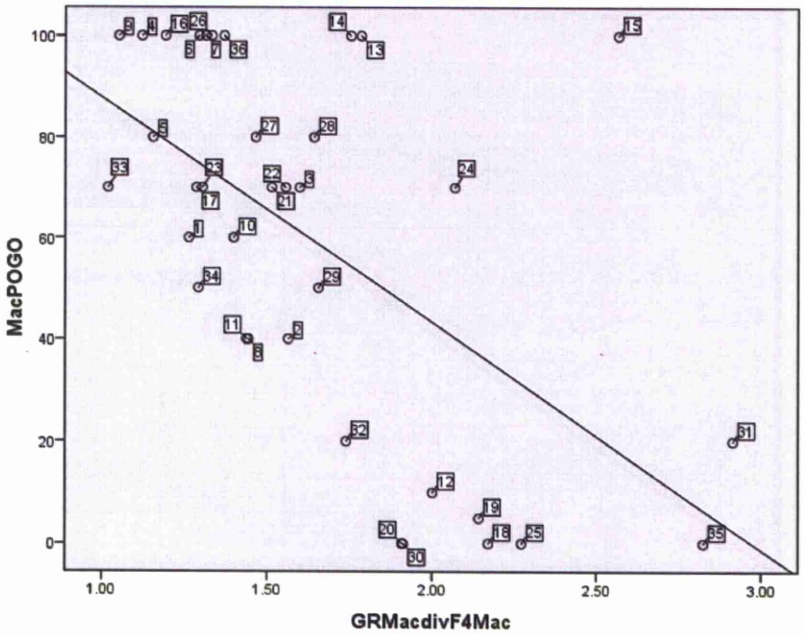

Figure 65 Scatter plot of Macintosh POGO versus GR/F ratio (GRMacdivF4Mac) for Macintosh.

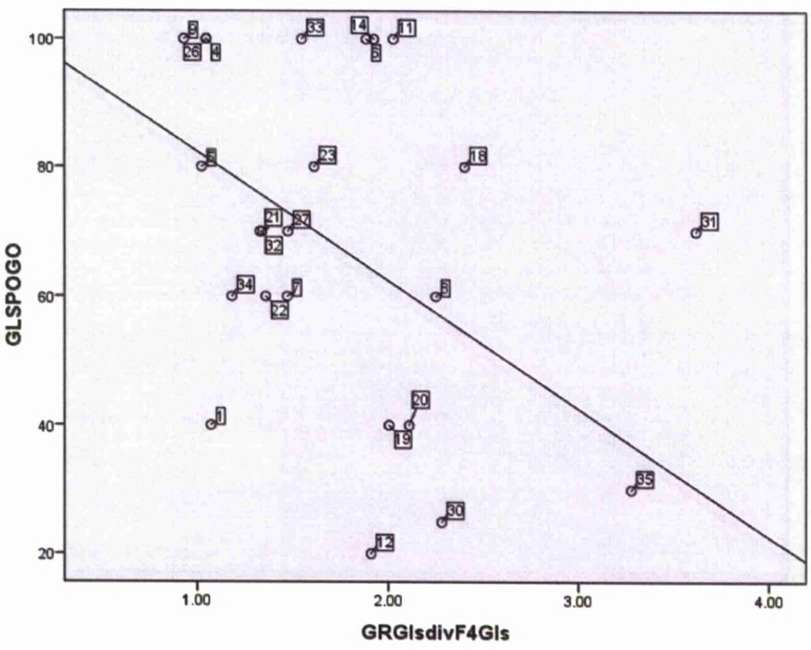

Figure 66 Scatter plot of Glidescope POGO versus GR/F ratio for Glidescope. Line is for regression equation after Case 31 was removed from the analysis.

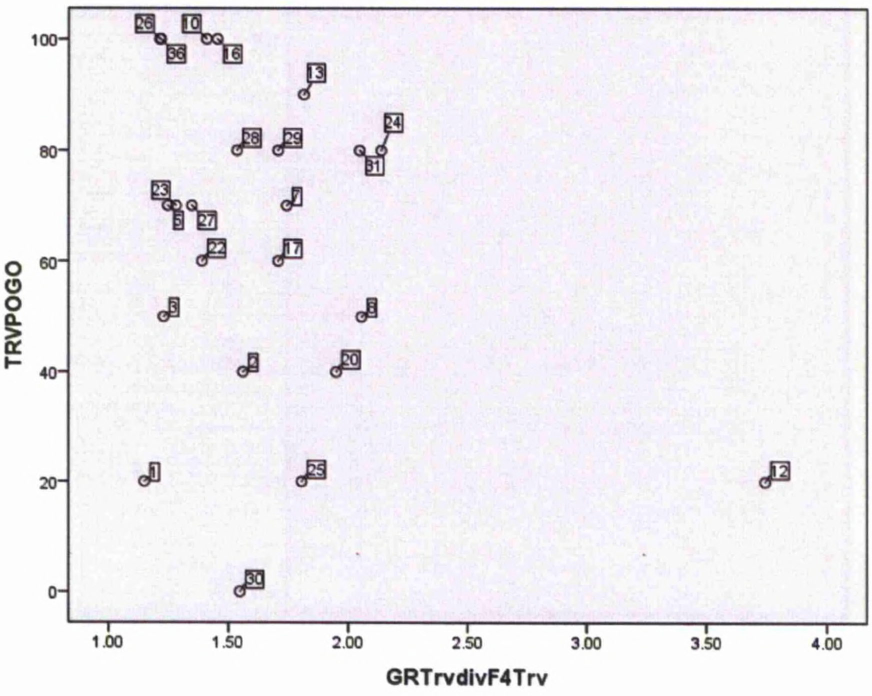

Figure 67 Scatter plot of Truview POGO versus GR/F ratio for Truview

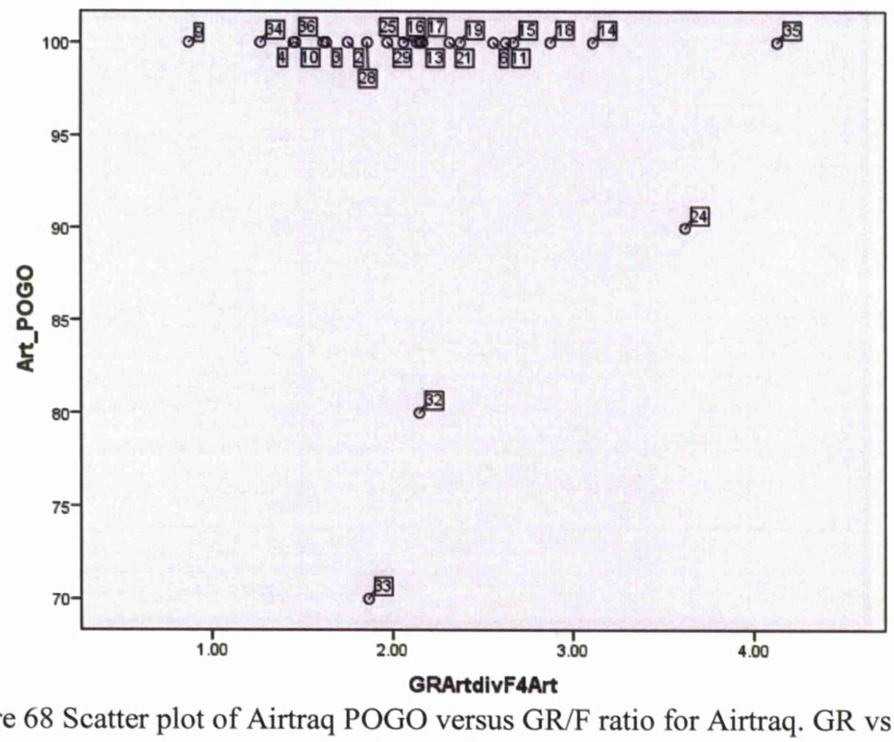

Figure 68 Scatter plot of Airtraq POGO versus GR/F ratio for Airtraq. GR vs F match didn't have any relation to the view obtained.

f. Correlation of JIST angles with GR area measures for each blade

Angle	Mac_GR	GLS_GR	TRV_GR	ART_GR
HTI	P=0.002 Mac_GR = 44.31 -0 .45*HTI_Mac	P=0.01GLS_GR=47.46 – 0.56*HTI_Gls	ns	ns
IST	ns	Ns	ns	ns
ITS	ns	Ns	ns	ns
JXT	ns	Ns	ns	ns
SXT	ns	Ns	ns	ns
JIT	ns	P=0.002GLS_GR=-5.56 + 0.48*JIT	ns	ns
TIS	ns	Ns	ns	ns
IJT	P=0.004 Mac_GR = 49.96 -0.31*IJT_Mac	P=0.000GLS_GR=58.4 – 0.421*IJT_Gls	ns	ns
IJS	P=0.005 Mac_GR = 46.17 -0.62*IJS_Mac	P=0.006GLS_GR=42.1-0.4*IJS_Gls	ns	ns
SJT	P=0.016 Mac_GR = 45.79 -0.41*SJT_Mac	ns	ns	ns
ITJ	ns	ns	ns	ns
Stepwise	P=0.002 Mac_GR = 44.31 - 0.45*HTI_Mac	P=0.000GLS_GR=58.4 -0.42*IJT_Gls	NA	NA

Table 14 Relationships between individual angles and GR area for each blade, showing p values and regression equations

Section D: Case demonstrating Peardrop effect (Case 25)

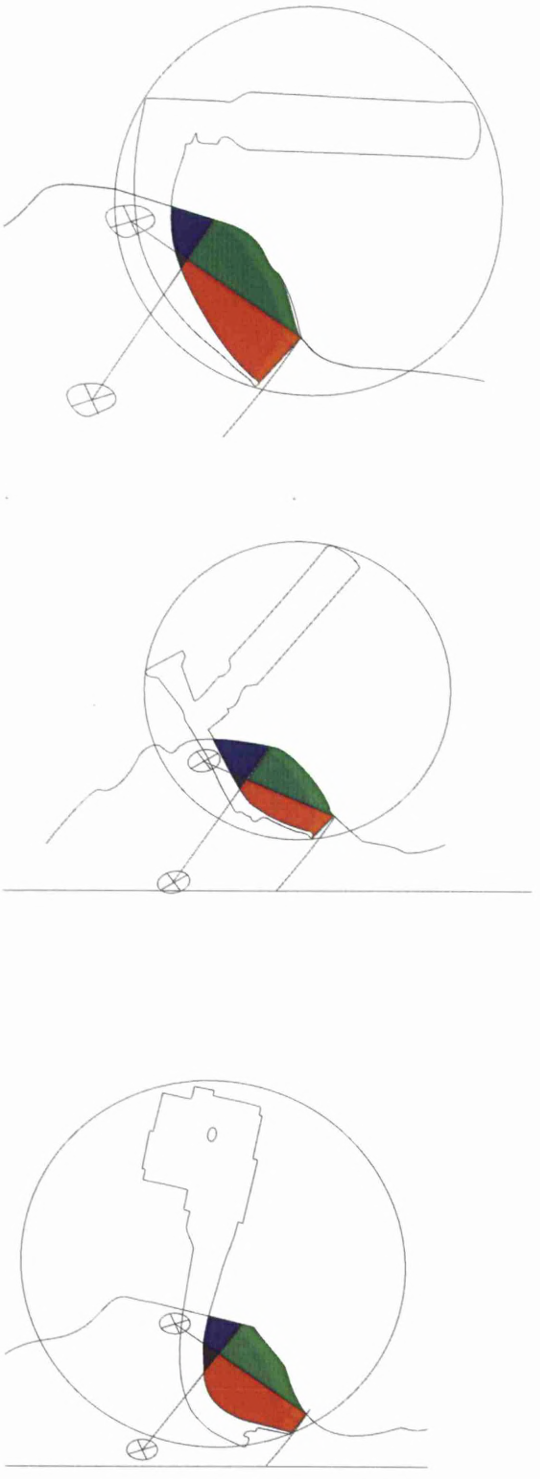

Figure 69 Case 25 Overlays showing Macintosh, Truview and Airtraq blade positions with individual area mapping

In case 25, Macintosh laryngoscopy resulted in no laryngeal view and the epiglottis appeared immobile and fixed to posterior pharyngeal wall (the characteristic description of the 'Peardrop effect'). POGOs for Truview and Airtraq in the same case were 20 and 100 respectively. Overlays of these three laryngoscopies were as above (figure 70). The eyeline deviation for Macintosh was 21deg. And the F value was 14.6. The overlay for Macintosh is suggested to reflect the whole principle of Peardrop effect where the blade tip is progressively rotated backwards because of the size of the IRV.

5.4 Discussion

This clinical study in 36 patients undergoing routine ENT surgery proved that Airtraq was the most successful device and Macintosh was the least successful as far as POGO view was concerned. According to Arne et al ENT surgery is considered as a risk factor for difficult intubation. [65] In our study to maintain consistency for lateral photographs and subsequent overlays Macintosh laryngoscopy needed to be performed in sagittal plane to avoid rotation of the handle and blade from the midline. This probably increased the likelihood of poorer views with Macintosh laryngoscopy but was needed for true blade comparisons. The functional limitations of Macintosh have been described in terms of need for tongue displacement and the space available into which this displacement can occur. This has been described as a "final common pathway for difficulty". [45, 60] A "Peardrop phenomenon" occurs when the tongue is pushed down into the pharynx and wedged between the inner surface of mandible and the under surface of the blade resulting in fixation of epiglottis to posterior pharyngeal wall and, as a result, no laryngeal view. This is found when the submandibular space is markedly compromised. The Overlay method has proved to be the most important confirmation so far for this mechanism, in showing that a progressive partial effect occurs regularly with normal Macintosh laryngoscopy use. This was very well illustrated in our results as POGO view worsened as the blade-eyeline deviation angle (angle TIL and TEL) increased. Furthermore, the overlay method has also proved useful for demonstrating "Mac-alike" behaviour in Glidescope and Truview and a quite different pattern with Airtraq.

The Overlay method was based on the earlier mathematical JIST model. The main limitation for replicating this model was determining an 'S' point equivalent, because the method chosen to do this (using a shaped straw) proved inconsistent. (The S point in original model was an X ray derived bony point on the internal midpoint of mandibular symphysis. For this study, S was derived from an extension of line JX to the skin through X, a point on IT 2/3rd of the way up from T. This 2/3 ratio was taken directly from the average value in the original JIST model and has also been used in a blade design paper.[44] Having adopted this convention, it proved to be especially useful for tongue area mapping, and added another novel aspect to the methodology. It then made sense to relate the new colour coded areas to the JIST model because the colour divisions have a specific role in Macintosh laryngoscopy.

The Green-Red (GR) combined area is a 2-D representation of the Inevitable Residual Volume (IRV) of the tongue (originally described in the context of Macintosh laryngoscopy as that part of the tongue remaining anterior to the blade and needing to be accommodated in the space available in order to expose the larynx). This combined area was important not only because of its size but also due to the relative contributions of Red and Green. Overall size was not different between Truview, Glidescope and Macintosh, implying that their IRV's and in some sense, blade functionality were equivalent. This is considered to be an extremely important result in terms of how the individual blades compare in respect of functionality versus optical advantage. Airtraq was obviously quite different with GR area much larger than Macintosh, so implying a greater IRV.

When the individual Green component areas were considered, the force applied to the IRV seemed relevant because of associated bulging outwards of the skin over the neck. Mean Green area values were least with Airtraq and greatest with Macintosh. Truview was closer to Macintosh and Glidescope midway between Macintosh and Airtraq (results consistent with the earlier Simulation Study when subjective force at laryngoscopy was greatest with Macintosh and least with Airtraq.) On the other hand, the size of the Red area was largest with Airtraq with no difference in Red areas between Macintosh and Truview or between Glidescope and Truview. For Macintosh in particular, size of the Red area affects the view at laryngoscopy because as this area increases, the blade is pushed backwards and the view is diminished as a result. While a similar pushing backwards on the blades was seen with Glidescope and Truview, here the view is also be influenced by their optical systems and so the effect on the POGO view was less marked. The size of the Black area was generally related to the size of Red area and smallest for Macintosh. Increase in black and red areas was associated with reduction in POGO view due to backwards displacement of the blade.

Indirect laryngoscopy has been described as an attempt to "see around the corner". [66] With the Macintosh direct laryngoscopy this is frequently impossible and reference is made to the need to "align the three axes". [67, 68]Theoretically the most efficient optical system for an indirect laryngoscope would be to have its "eye" close to the posterior pharyngeal wall looking straight down to the laryngeal inlet with no tongue in the way. (Rather like a rigid bronchoscope used in the angle of the mouth.) With Macintosh the tongue has to be forced out of the way and hence the "final common pathway" for difficulty where the degree of backwards displacement away from IT determines the view obtained. Pairwise comparisons between IE, ET, and angles EIT and IET, showed no differences between Glidescope and Truview, but a consistent pattern of differences between Airtraq versus both Glidescope and Truview with the Airtraq "eye" nearer T and further away from IT. In other words Airtraq is more like the ideal "seeing around the corner" indirect laryngoscope while Glidescope and Truview are more like Macintosh because they have the same basic limitation by way of backwards displacement.

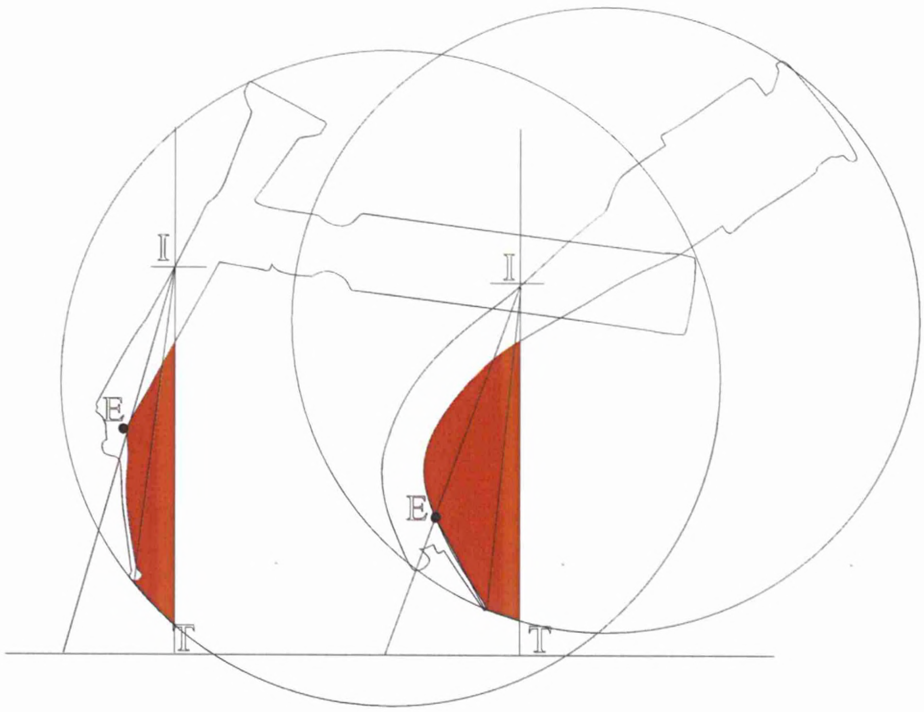

Figure 70 Mean disposition of Truview and Airtraq blade tips and 'eyes' (E) in relation to IT

I=Incisor point and T= tracheal point with T at the same horizontal level and incisor points vertically above at the mean distance from T. Although angles EIT are relatively similar, the red area for Airtraq is clearly greater because its 'eye' is below maximum blade curvature which allows more tongue to be accommodated above this 'eye' position.

For Airtraq the IRV becomes much greater and less force is applied to the tongue. Despite this the POGO values were better than all the other blades. If the effect of the "eye" and distal straight segments of the IDLs is considered, the matter becomes a more clear (figure 71). From this diagram it is obvious that the more proximal position of the Airtraq "eye" allows a much greater size of Red area while still being able to look at the airway point T. Because the TELangles are similar (table 11), the main optical difference is due to the fact that the Glidescope and Truview "eyes" are more distal so any displacement of the "eye" backwards will have a greater implication for laryngeal view than an equivalent backwards displacement of the Airtraq "eye".

Analysis for linear JIST measures showed that JI, JS and JT correlated to Mac POGO and Mac GR area. Line JI also correlated with Glidescope POGO but there was no relation between any JIST lines for Truview and Airtraq POGOs. Simple Scatter Graphs showed simple homogeneous relation in JS, JI and JT in the subjects studied (i.e. there were no unusual anatomical abnormalities) and these distances were closely correlated with one another. (JI and JS should be related for normal mouth closure and JS and JT are expected to be related because during swallowing hyoid moves up and fits into the internal mandibular shape). [(69)]In that sense, JS, JI and JT can be seen to be like pages of an open book within which the IRV and blade are placed during laryngoscopy. How this book opens or closes its pages will be influenced by relative head/neck movements and mouth opening. These dynamic relations were described by the angular measurements.

Angle IJT showed significant correlations for both Mac POGO (positive) and GR area (negative) with equivalent correlations for Glidescope POGO and GR area. Angle IJT can be considered to represent head/neck relationships at laryngoscopy. As angle IJT increases, the submandibular space opens up so if the IRV is unchanged the view should improve. With Truview and Airtraq POGO there were no significant angular correlations. This implies that Glidescope has more Mac-alike functionality as far as IJT and the effect on POGO view is concerned.

Analysis of areas versus angles and lines allowed an "F" value computation to compare this work with the earlier mathematical model. In that JIST model F was calculated as shown in the Results and it is independent of subject size. Allowance has to be made for the fact that point S in this analysis was different from the original JIST model. Previously an F value below 15 was suggested to be a critical marker for difficult intubation and F represents the space available to accommodate IRV. Macintosh POGO was positively correlated with F. For Glidescope, Truview and Airtraq POGO, however, the F value was not correlated. F computations make no allowance for the optical systems of these devices, so even if a space accommodation difficulty existed the optical properties might disguise this.

In the pre-operative factors analysis, POGO scores for Macintosh was summarized in a stepwise regression showing inter-incisor and inter-condylar distances in the relevant model. This could be interpreted as meaning that a wide mandible (and presumably a large tongue) needs to be offset by good mouth opening else the POGO will suffer. Another model for POGO view with Macintosh relating to the backwards displacement of the blade involved TIB and IT (section 3.a). From the pre-operative factors analysis IT had a relationship to height and neck extension angle whereas TIB was strongly related to BMI and neck extension. In considering the relationship between mandibular size and GR area (Results section 3.b), an alternative and more consistent relationship for all four blades involved ICD and ExtCond-to-IntSym. For the first time, this model allows an estimation of IRV based on pre-operative factors. In the same way the pre-operative factors also appeared to have some value in suggesting the space into which the IRV could be accommodated. Stepwise regression for Macintosh F value involved intercondylar distance and neck extension. Equivalent models were also possible for Glidescope and Aitraq (section C.c).

Overlay Analysis for area versus angles and lines and then F values helped crystallize the concepts of submandibular space (F value) and tongue size (GR area) with respect to the limitations for the Macintosh blade. GR area is a 2-D representation (midline sagittal) of the IRV, the volume of tongue which remains in front of the blade at laryngoscopy. This volume needs to be accommodated, principally in the submandibular space which F estimates. When F is relatively small, the Macintosh blade cannot approximate to the IT line and the view of larynx is diminished accordingly. In other words an increased GR area/ IRV ratio prevents the blade from moving forwards to IT so limiting the POGO view (Result, Section C.e). In the graphs (figures 66 to 68) there appears to be a simple linear relationship for both Macintosh and Glidescope POGO versus the relevant GR/F ratio where a small ratio is associated with a high POGO score. The graph for Airtraq has no obvious pattern in that the POGO score is nearly always 100 and the ratio is fairly irrelevant. For Truview with one exception (case 12) the ratio seemed to be tightly bunched with no obvious effect on the POGO score. (In the graphic relationships for GR area versus F value (figures 62-64), Truview was the only one where these were not linearly related.) The Overlay analysis proved to be in line with and helped to further understand the JIST model as well as provide detailed confirmation of the Peardrop effect.

The aim of this study was to determine factors influencing indirect laryngoscopy relative to Macintosh and it was possible to suggest both Mac-alike and non Mac-alike behaviour. Firstly form the point of view of eyeline deviation angle, POGO view worsened, as this angle got bigger for both Macintosh and Glidescope but not Airtraq or Truview. While GR area was not different between Macintosh, Glidescope and Truview, it was much larger for Airtraq. The Red area component was largest with Airtraq and smallest for Macintosh with Glidescope and Truview in between (and similar to one another). For the Green area Airtraq was smallest and Macintosh largest and again Glidescope and Truview in between (and similar). Angle IJT and line JI also showed correlation with Glidescope POGO similar to Macintosh but this was not the case for Truview or Airtraq. In conclusion it is clear that Airtraq had totally unique functional profile that is different from Macintosh while Glidescope and Truview are somewhere in between. There were more Mac-alike properties for Glidescope than Truview and in that sense Glidescope should be considered generally more Mac-alike than Truview.

As far as the overlay method was concerned this clearly showed great promise for the analysis of underlying mechanisms in direct laryngoscopy and comparison between IDL blades. It showed clearly why Airtraq has advantages over both Glidescope and Truview. This was the first full use of the method and there is great potential for improved accuracy in the future plus the likelihood of increased compatibility with the original JIST model. The increasing accuracy will provide a big stimulus for advances in the virtual laryngoscopy model being developed between this Department and that of Professor Duncan Gillies at Imperial College. [70]

Section 6

Thesis Summary

Indirect laryngoscopy has evolved from simple prisms and mirrors to present day sophisticated lens/prism complexes and fibreoptic technologies. This evolution came about to address the limitations of Macintosh direct laryngoscopy i.e. failure to always provide an adequate laryngeal view (in 6 to 10% of intubations, with failed intubations in about 0.13-0.3% of cases). Manufacturers and designers seized this opportunity and at the same time perceived a potential for blade design "improvements" even though there was no obvious scientific basis on which to do this. Previously, the limitations of Macintosh laryngoscopy have been described in terms of a tendency to a "peardrop effect" in the context of a 'final common pathway' for difficulty. This thesis aimed firstly to confirm the functional aspects of Macintosh laryngoscopy and then to compare indirect laryngoscopy in order to determine their functional (Mac-alike behaviour) versus optical advantages. A combination of bench studies, simulation studies (with AirSim and Leardal SimMan) and a finally a clinical study (involved 36 patients) were used.

Optical advantages need to be considered relative to the proximity of the effective viewing position from the blade tip, clarity of the display and image distortion or restriction. The initial studies concerned the field of vision (FOV) and image display. Truview had the smallest FOV, sufficient to have implications for tube delivery. Although Airtraq had the largest FOV, its design only allowed a tube to be directed onto a small target zone in this FOV. If the laryngeal inlet doesn't happen to be in this zone, adjusting Airtraq appropriately may improve the situation. However in clinical practice such manoeuvring may not always be feasible and at least will add to the learning curve for this device. FOV images were shown to be distorted when alignment of the blade tip was not at right angles to the plane of the inlet.

For direct line of sight devices like Macintosh the tongue needs to be displaced and the view obtained depends on the degree of eyeline deviation from the ideal anterior airway. Simulation of the peardrop effect is possible when tongue displacement is limited either by its size or the space into which it can be accommodated. Using the AirSim manikin, tongue size/space match was progressively reduced by a combination of increasing tongue volume (i.e. size) and increasing neck flexion (i.e. reduced space). The results showed that with Glidescope and Truview the view depended on whether they exhibited a similar tongue displacement profile i.e. a tendency to a peardrop-like effect with reduced space. Airtraq on the other hand had an impressively different tongue displacement profile in the sense that a partial peardrop effect occurred with much worse conditions than for the other blades. At the same time the force needed for an optimal view with Airtraq was also less than with the other blades.

Another aspect of Macintosh laryngoscopy is that, under ideal circumstances, it has good tracheal alignment to assist in positioning the tracheal tube. This is helped by the "all round view" which is not available with the indirect laryngoscopes. In the AirSim study all the indirect laryngoscopes were closely aligned with the tracheal axis in moderate extension. Only Airtraq had negative values for this alignment with any degree of head extension. (This could have implications for manoeuvres with Airtraq to improve tube delivery in clinical circumstances.)

A novel simulation of graded difficulty in Lardeal SimMan was developed to produce progressive reduction in the space available for tongue displacement. This model was validated for Macintosh with 20 anaesthetists who also performed IDL laryngoscopies. This model suggested that Glidescope, and to some extent Truview, are functionally similar to Macintosh and suffered from similar limitations in the difficult setting. Truview showed less worsening than Macintosh and gave a better view in the difficult setting. Airtraq was the most successful with the added advantage that less force was needed. As has been noted by other workers, the view obtained did not equate with ease of intubation for indirect laryngoscopes. A new index, the DELI score, was proposed to quantify the difference between ease of laryngoscopy versus ease of intubation. This measure highlighted a positive feature for Macintosh that in general was lost for the indirect laryngoscopes.

The clinical trial was designed to determine the clinical relevance of the features in the simulation studies. The overall analysis was based on the earlier JIST mathematical model for difficulty and this was facilitated by use of the novel method of the overlay technique. The first result was a clear confirmation of the peardrop hypothesis because in normal use the main limitation with the Macintosh blade was a mis-match between the tongue inevitable residual volume (IRV) and the space available to accommodate it. The resultant effect was progressive backwards displacement of the blade tip away from the ideal eyeline view. This phenomenon also occurred with the indirect laryngoscopes but to varying degrees their optical systems tended to overcome the effect, most notably with Airtraq. The novel use of area segments was based on an initial limitation due to failure of the original method to determine the actual position of the "S" point in the JIST model. However this proved extremely useful in quantifying the analysis of IRV and the space into which it is accommodated. The green-red (GR) areas for Macintosh, Glidescope and Truview were the same (itself an important result) but bigger with Airtraq despite it generally resulting in a better POGO view. Clearly Airtraq has a very different functionality compared with Macintosh (and the other blades) under these circumstances.

To explain the success of Airtraq despite the increased GR area it was important to consider the position of the effective "eye" and overall blade shape. In effect its short distal straight segment meant its eye was closer to the laryngeal inlet and more particularly was always beyond the main bulge in shape of the device. This not only allowed a bigger tongue volume to be accommodated, but the "eye" no longer needed to see around the IRV because it was already below the greater part of it (as opposed to Macintosh which was displaced backwards because of it).

In conclusion this thesis proved the everyday relevance of the peardrop hypothesis, and showed its relevance to the current indirect laryngoscopes. The IRV is very important for all these devices and for Glidescope and Truview was no different than for Macintosh. The new optical systems address this problem to some degree but it was only Airtraq that tended to bypass the problem altogether both with its optical advantages and a shape that allowed a much greater IRV to be accommodated.

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S Darshane became S Charters, Oct 2010.

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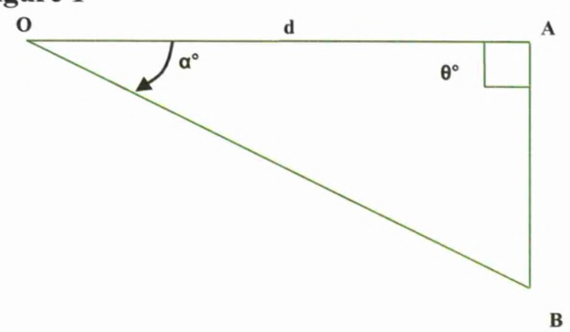
Section 8

Appendix A Calculations to determine individual square sizes

a. Calculations to determine individual square sizes – vertical values

Figure 1 represents the distal straight segment of an IDL blade (OA, length d) with its tip (A) touching a board (AB) at right angles to OA and whose length matches the FOV, described by angle α. When the board is rotated away from OA about A (angle $\theta^{o} > 90^{o}$), AB still represents the IDL viewing screen while the new board position is AQ. On the screen, the board looks smaller (AC), while AQ=AB (see figure 2).

Figure 1

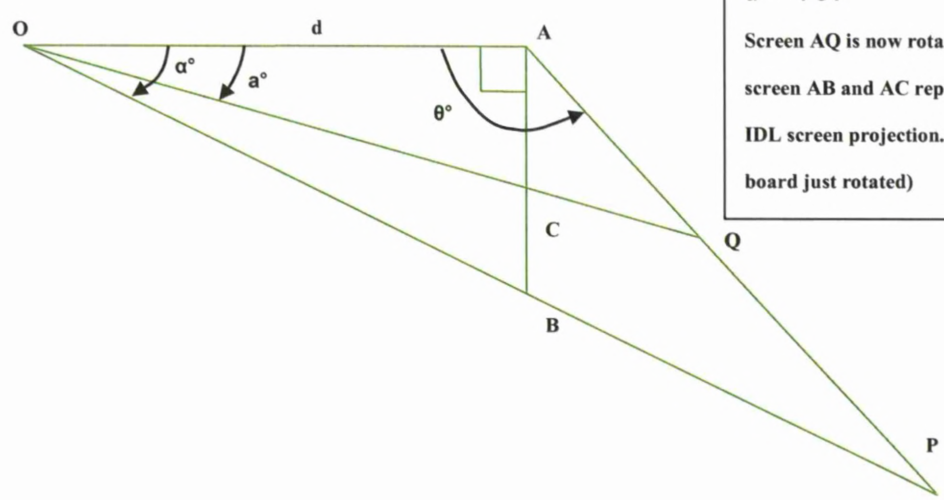


OA = d, distal straight segment

α° = FOV

The board (AQ) and Screen AB are co-incident

Figure 2

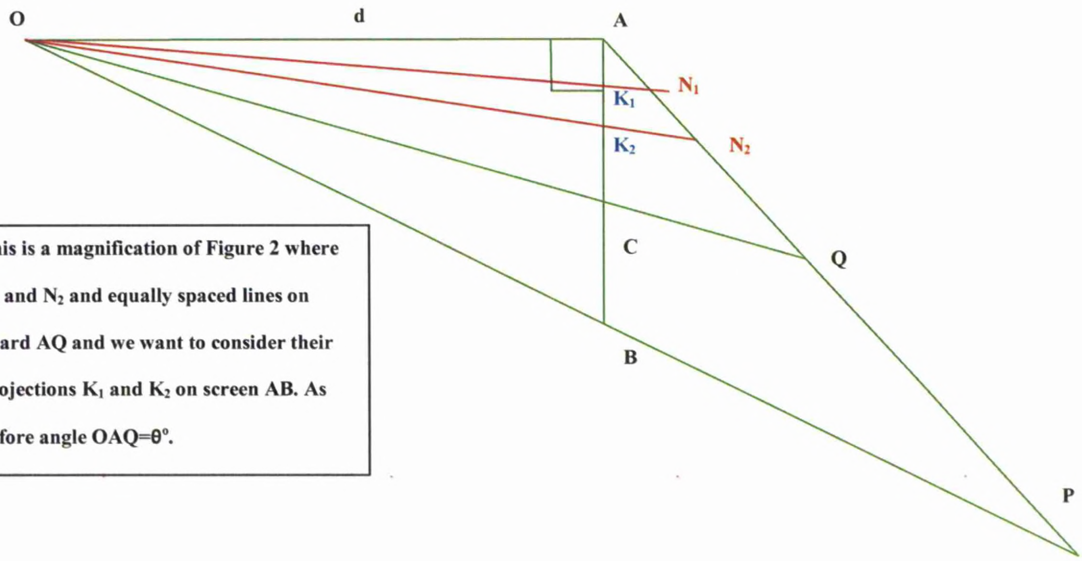


OA = d, distal straight segment

α° = FOV

Screen AQ is now rotated back from screen AB and AC represents the new IDL screen projection. (AB=AQ as board just rotated)

Figure 2a



This is a magnification of Figure 2 where N_1 and N_2 and equally spaced lines on board AQ and we want to consider their projections K_1 and K_2 on screen AB. As before angle OAQ=θ°.

If AQ has n equal segments of size n=0.5cm: N_1, N_2, N_3 ... we can draw triangles for each, OAN_1 etc. where angles AON_1, AON_2 etc all have the same size.

For the first triangle OAN_1:

Let us call angle AON_1 = a1, and angle AN_1O = n1

Now n1=(180-θ-a1) and by the sine rule:

Sin (a1) / (n) = sin (180-θ-a1) / (d) $(AN_1=n)$ EQ1

Taking sin (180-θ-a1) as the difference between angles (180-θ) and (a1)

Sin (180-θ-a1) = sin (180-θ).cos(a1) – cos (180-θ).sin(a1)

= sin (θ).cos(a1) + cos(θ).sin(a1) EQ2

Substituting EQ2 into EQ1

Sin (a1) / (n)= (sin (θ).cos(a1) + cos(θ).sin(a1)) / (d)

Dividing through by sin (a1) gives

$d / n = \sin(\theta) / \tan(a1) + \cos(\theta)$ EQ3

If K_1 is the representation of N_1 and we let $AK_1 = k1$, then $\tan(a1) = k1 / d$

Substituting in EQ3 and re-arranging now gives

$k1 = n.d.\sin(\theta) / (d - n.\cos(\theta))$ EQ4

Now if we consider triangle OAN_2, the equivalent result becomes

$k2=2.n.d.\sin(\theta) / (d-2.n.\cos(\theta))$ because $AN_2 = n \times 2$

Now consider the ratio $k1/k2 = (d-n.\cos(\theta)) / 2(d-2.n.\cos(\theta))$ and as expected when $\cos(\theta)=90$, $k1/k2 = 0.5$ but as $\cos(\theta)$ becomes progressively larger ($90<x<180$), the relationship is influenced more by increasingly positive values for the demoninator so K_2 decreases in size relative to K_1

If, on the other hand, the board becomes rotated closer than the screen, so that $\theta < 90°$,

EQ2 becomes $\sin(180-\theta-a1) = \sin(\theta).\cos(a1) - \cos(\theta).\sin(a1)$

and this leads to the relationship

$k1 = n.d.\sin(\theta) / (d + n.\cos(\theta))$ and similarly $k2=2.n.d.\sin(\theta) / (d+2.n.\cos(\theta))$ so we have the ratio $k1/k2= (d + n.\cos(\theta)) /2(d+2.n.\cos(\theta))$

Here when $\cos(\theta)$ becomes progressively smaller ($90<x<0$) so the denominator gets smaller relative to the numerator, i.e. cell height gets larger the nearer the board AB is to OA.

b. Calculations to determine individual square sizes – horizontal values

Figure 3 is equivalent to Figure 1, set up to consider the horizontal measures.

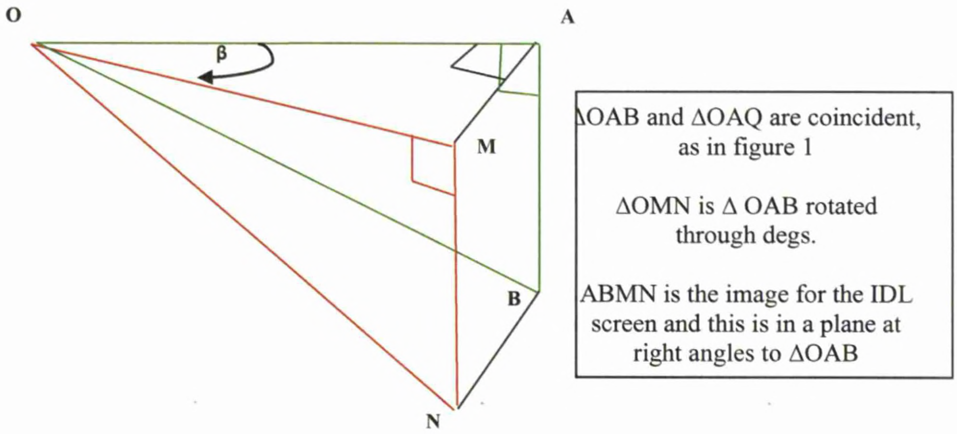
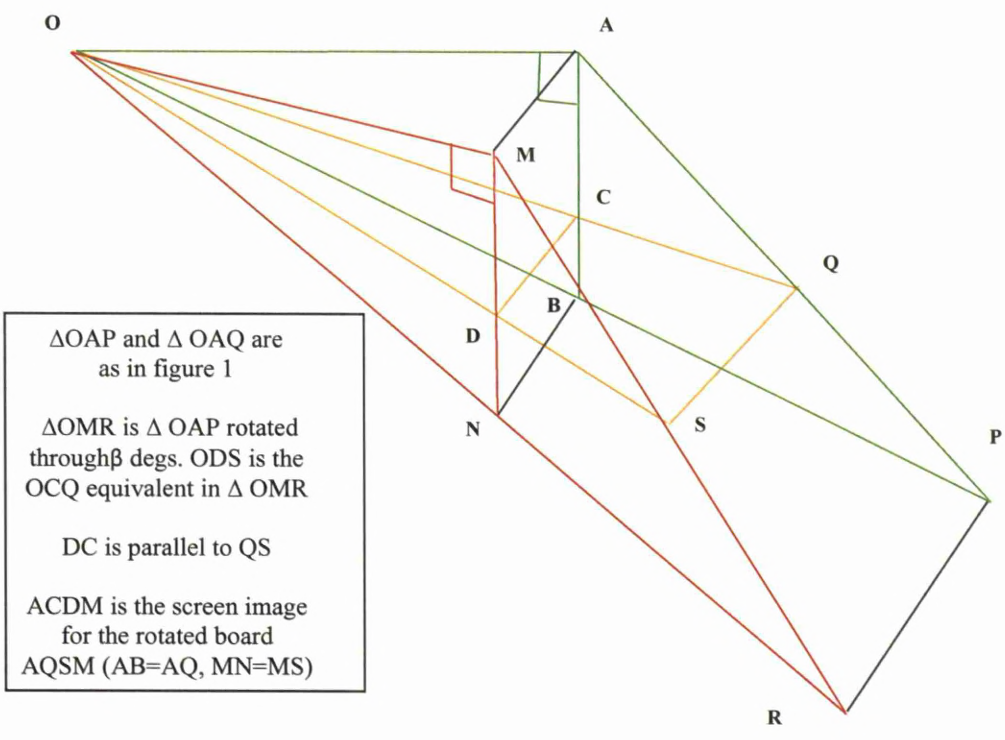


Figure 3a is a repeat of figure 2 with the horizontal measures included. The IDL lens systems view from the plane of figure 2 (OABQ) and in the neutral, 90° position, the plane MABN is at right angles to plane OABQ, joined along line AB. Again in this position, the board size matches the IDL's FOV.

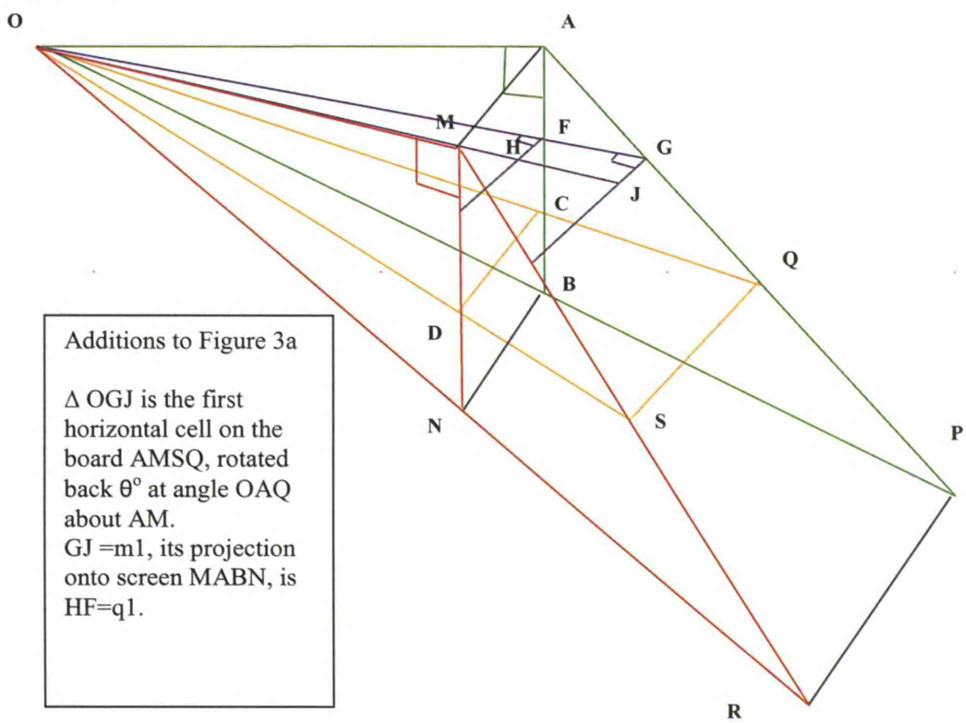
Figure 3a



If similarly to above we now consider m 0.5cm segments along the rotated board, the projected q1 = HF is found from the following (figure 4) triangle OJG where JG=m1:

HF / JS =q1/m1 = OF / OG (similar triangles)

Figure 4



As in figure 3, OAG = θ^{o},

Sin (θ) / OG = sin (a1) / n1 and d / OF =cos (a1)

Hence, $q1 = m1.(d / \cos(a1)) / (n1.\sin(\theta) / \sin(a1))$

$q1 = m1.d.\tan(a1) / (n1.\sin(\theta))$ and as above $\tan(a1) = k1/d$, so

$q1 = m1.k1 / (n1. \sin(\theta))$ EQ5

If we consider the second segment along,

$q2 = (m2.d.k1 / (n1.\sin(\theta))$ and $m2= 2 \times m1$ so the horizontal cell sizes on any given n1, n2 etc. are constant for that particular n1, n2 etc.

Appendix B Overlay Method for clinical study

All the laryngoscopies were recorded with a lateral photograph (the "primary image") and in each case every effort was made to maximize the amount of the blade handle visible to the camera. Each primary image was then used to as the basis for an overlay diagram to demonstrate the relative positions of the laryngoscope blade, laryngeal inlet and temporo-mandibular joint (marked by position of external auditory meatus). In addition the patient's neck was marked at site of cricothyroid membrane and sternal notch. The former was used to predict the location of the laryngeal inlet. Standardised photographs of each blade (the "secondary images") were taken again in a lateral profile so that these could be overlain onto the primary images.

In effect all the photographs of interest were related to a single (median saggital) plane with the camera positioned at an appropriate distance from and at right angles to this plane. This distance was fixed for each photograph. The (laryngoscope) secondary images were processed using a computer graphics program (CorelDRAW™). Blade outline shapes were reproduced by Bezier drawings with suitable magnification for accurate reproduction. At this stage laryngoscope blade and handle length were measured accurately at fixed points so that the ratios could be checked against the secondary images. The outlines were then copied and transposed onto the primary images. As the secondary images would need to be sized, translated and rotated without distortion, they were individually enclosed by a surrounding circle (touching at least three perimeter points of the blade) and then the circle and blade image were grouped for subsequent manipulations.

When the initial lateral photographs were taken (at maximum laryngeal exposure) a further check photograph was always taken from the foot of the patient to make sure that laryngoscope handles were positioned in the midline. In the small number of cases where this was not so, correction was possible by having backup secondary images of the blades with appropriate allowance made for this error. (This required additional bench work to ensure that the images were properly corrected.) For each primary image a template was created consisting of (Bezier) outlines head and neck, that part of the laryngoscope blade that was visible, laryngeal inlet line (drawn from previously marked cricothyroid membrane) and external auditory meatus. This master template was set in a rectangle of fixed dimensions so as to have uniformity for all the images. Next the secondary image of the relevant laryngoscope laryngoscope blade was positioned onto this primary image so as to be coincident with that part of the blade that was visible on the original image.

Individual secondary and primary images were colour-coded and for comparisons for between-patient laryngoscopies they were superimposed and lined up so as to have the anterior laryngeal lines coincident. This created a complete patient file for export to Microsoft Office software.

Appendix C Method used for area mapping

In CorelDraw load vector diagram. Get co-ordinates for IT (say x1,y1 and x2,y2). Calculate the intersection point (x3,y3) where the new line will cross this i.e. $x3 = (x1-x2)*1/3 + x2$ assuming $x1 > x2$ and the same for y3.

Draw a new line from x3,y3 to the TMJ point and use magnification x400 for precision. Then draw a newline superimposed on this where one point coincides with TMJ point and the other end makes contact with the skin. This line should be altered so as to be directly over the first line.

<u>Outline Quadrant 4</u>

General rule is to use best tangent to tip above/below the point of the tip (e.g. the upper half of the spherical blade tip) according to whether tip is in front of IT or just behind it respectively. This leads a minor anomaly when the blade tip just touches IT (when the upper part of the tip is used) because just before this, the lower part is used (i.e. there is a sudden jump in values). It does however avoid the possibility of more than one "red zone". For Airtraq where the tip is smaller the central point was first choice or the best tangent otherwise.

The quadrants are filled:

Green (Red=0, Green=255, Blue=) for the submental region in front of IT

Red (Red =255, Green=0, Blue =0) for the region behind this

Blue (Red=o, Green=0, Blue=255) is the region above the green zone

Black (Red=o, Green=0, Blue=0) is the region behind blue and above red.

The image is coped at 150x magnification so that IT is preserved with the outlined quadrants

This cropped file is saved as a TIFF bitmap at 500dpi (preserving aspect ratios)

The bitmap imaged is loaded into the AnalysingDigitalImaging software where it is sized against the actual IT measure. Masks are chosen to outline the relevant quadrant. The rectangle shape is used to contain the masked quadrant and the area is then reported by the software.

Appendix D Distribution of pre-operative measurements for patients

Pre-op measurements	Range	Min	Max	Mean	Std. Deviation
Height (cm)	40	147	187	166.558	8.4424
Weight (kg)	61	46	107	75.75	17.338
BMI	20.3	17.3	37.6	27.107	5.0293
ArmSpan (cm)	41	146	187	167.556	8.5061
Inter-incisor distance (cm)	3.4	2.7	6.1	4.636	0.6867
Inter-condylar distance (cm)	6.3	10.2	16.5	13.742	1.1614
ExtCond-to-IntSym (cm)	4.3	10.5	14.8	12.539	1.0519
NeckExtension (degrees)	41	21	62	39.33	11.074

Table showing the pre-operative measurements recorded. "ExtCond-to-IntSym" was a caliper measure of the distance from the surface of the mandibular condyle to the mid-point of the internal surface of mandibular symphysis. Neck extension was measured using an angle finder device against a reference horizontal line drawn on the side of the face forward from the external auditory meatus.

Appendix E Glossary

Alignment (laryngoscope blade)

This describes the relative angulation between the distal straight segment of the laryngoscope blade and the plane of the object of interest it is attempting to line up with. At an alignment of ninety degrees to the laryngeal inlet, there will be minimal distortion of the laryngeal view by the optical system in question.

Angulation (laryngoscope blade)

The relative change in angle between the laryngoscope blade immediately before and immediately after the start of the distal straight segment.

Anterior airway line, IT

A line drawn from the I point to the T point. It represents an ideal straight line view to the laryngeal inlet.

Area analysis (for the photographic overlay technique)

In the photographic overlay technique, a new method for analyzing the tongue volume was developed. It is again based on the JIST model with four defined areas: green; red; blue and black determined by the JS and IT line intersection. The boundaries are the lingual surface of the laryngoscope blade and the neck skin inferiorly. Green is the antero-inferior; Red is postero-inferior; Black is postero-superior and Blue is antero-superior.

Channel device

This describes a subclass of indirect laryngoscopes, IDLs, that have tube delivery channels. When IDLs are not able to provide direct line of sight views of the laryngeal inlet, the tracheal tube still needs to be safely delivered into the field of vision. However, because this will inevitably also be relatively blind, tissue injury related to blind tube delivery is possible. Channel devices tend to circumvent this problem by allowing pre-loading of the tube into the device channel and then delivering the tube directly into the field of vision once the larynx is identified. (An alternative description for channel devices is para-tubal delivery devices.

Distal straight segment

The measured length of that part of the indirect laryngoscope blade which is distal to the position of the video-camera.

DELI (Difference between Ease of Laryngoscopy and Ease of Intubation)

This simple index aims to indicate relative differences in ease of intubation versus ease of laryngoscopy. It helps to represent difficulty noted with intubation despite an adequate laryngeal view, a well recognized problem when using IDL devices.

DOI, Depth of insertion of laryngoscope blade

A measure of the distance to which the laryngoscope blade is inserted into the airway. This needs to be relative to some landmark which is usually the maxillary incisor tip. The performance of the blade in terms of its ability to displace the tongue to visualize the larynx is influenced by this distance.

Ease of Intubation

To record the subjective degree of difficulty anaesthetists experienced while attempting tracheal intubation they were asked to report a VAS score, between 0 to 100 where zero is extremely easy and 100 is extremely difficult.

Ease of Laryngoscopy

To record the subjective degree of difficulty anaesthetists experienced while obtaining a view of the larynx they were asked report a VAS score, between 0 to 100 where zero is extremely easy and 100 is extremely difficult.

Eye- point for the blade

For an IDL device this represents where an observer would need to place the eye (or in this case a camera) to see what the laryngoscope blade presents to its viewing screen.

Eyeline deviation line (/ angle)

This describes the angular measure to indicate the deflection of the eyeline back from the blade tip due entirely to the curve of the blade. It varies with the actual blade shape and the depth of insertion of the laryngoscope blade.

F value

A derived measure based on the JIST model. Its calculated from the formula

F= 100 x XT/ IT x XS/ JS x sin (Beta), where Beta is angle SXT. Clinical experience has suggested that intubation becomes difficult when F values are below 15. The F valueestimates the space available to accommodate the inevitable residual volume of the tongue

Field of vision

This is an angular measure from the distal straight segment of a laryngoscope blade to the maximum view away from it. Measurement of this angle allows comparison of the view which is independent of the length of the distal straight segment.

Functionality

This generic term describes those factors that are considered important in understanding the actual mechanism involved in tongue control and making the laryngoscope blades more or less efficient. This deliberately excludes effects that are due to the different optical properties of the relevant IDL devices.

I point

The point in the median sagittal plane representing the tip of the maxillary incisors. This point is important for the JIST model. When using the photographic overlay method it was a requirement that this landmark remained visible and this was facilitated by using a dental roll tucked under the upper lip.

IDL (Indirect laryngoscope) devices

A laryngoscope device that does not depend on direct line of sight down to the laryngeal inlet. An optical system is used to present an image of the larynx so that the user delivers a tracheal tube towards it. While these devices usually present a clear view of the inlet, there may still be a problem related to the loss of direct line of vision because getting the tracheal tube into the field of view may be entirely blind. IDIs can be subgrouped as either steering or channel devices according to how the tube is delivered into the field of vision.

Insert-Custom made tongue restrictor device

This was a locally produced device used to create an intermediate level of difficulty for laryngoscope study in simulation. (Section4)

IID, Inter-Incisor Distance

The measured distance between the maxillary and mandibular incisors when the mouth is fully open. (The usual measure of degree of mouth opening used by anaesthetists.)

ICD, Inter-condylar distance

The measured distance between the mandibular condyles. It is used in calculating the JS distance in the JIST model.

Inevitable residual volume (of the tongue)

In normal laryngoscopy with the Macintosh blade, the main limitation is the tongue which needs to be displaced to one side. The inevitable residual volume is that part of the tongue which is not displaced and so has to be accommodated between the blade and the mandible or the space immediately below the mandible.

ExtCond-to-IntSym

This represents the distance from the internal midploint of the manibular ramus to the outer mandibular condyle. It was measured pre-operatively using a calliper. It is used in determining the length of JS in the JIST model.

J point

The point in the median sagittal plane representing the inter-condylar position. This point is important for the JIST model. In addition the point was approximated for the overlay laryngoscopy studies by a mark drawn on the patients in front of external auditory meatus.

JIST model

The original mathematical model to describe factors relevant to difficult laryngoscopy was based on x-ray laryngoscopy. Processing of the x-ray images allowed construction of lines, JI and IT which intersect at point X. In the midline sagittal plane these points are: I - the tip of the maxillary incisors; T - the anterior airway point; S - the internal mid-point of the mandible representing genioglossus insertion; J - the point midway between the two mandibular condyles. (See also, x-ray laryngoscopy)

Linearity of the viewing system

The extent to which the image of the object projected onto a viewing screen is magnified in a linear sense. (In Section 2.4 the object used was graph paper squares and the linearity was tested relative to alignment of the distal straight segment to the board on which the graph paper was mounted.)

Mac-alike functionality

A novel term to compare blades relative to their ability to function in the same way as the Macintosh blade so as to share or deal with its limitations. Most importantly this relates to the ability to deal with increasing size of the inevitable residual volume of the tongue relative to the space available into which it can be displaced.

Open path tube delivery devices

IDL devices that do not have channels for housing the tracheal tube and so need to have the tube "steered" into the field of vision.

Para-tubal delivery devices

IDL devices that have channels for housing the tracheal tube and which run parallel to the optical channel.

Peardrop effect (A mechanism describing difficult laryngoscopy with a Macintosh blade)

This is described in detail in the text in section 3.1.

Photographic Overlay Technique

This novel method was the analytical process used to determine the relative position of the laryngoscope blade tips when they would not normally be visible. It was replacement for earlier x-ray laryngoscopy studies and avoided the need for radiation exposure. While internal landmarks cannot be as easily determined, the principal advantage of the new method was more direct inter-laryngscope comparisons than the earlier method. (See also JIST method.)

POGO (Percentage of Glottic Opening) score

This subjective index records what percentage the anaesthetist considered as that part of the larynx was seen at laryngoscopy relative to a scale on which 100% would count as the entire span from the anterior commissure to the interarytenoid notch of the vocal cord.

S point

The point in the median sagittal plane representing the mid-point of the internal surface of the mandible inter-condylar position. This point is important for the JIST model. For the photographic overlay method this point was substituted by an external equivalent. Firstly the line IT was drawn and then from a previous observation point X was marked two thirds of the way up from T. The line JX was drawn and extended to the surface of the skin where the substitute point for S was positioned.

Steering devices

This describes a subclass of indirect laryngoscopes, IDLs, where the tracheal tube is advanced (steered) without any directing channel. The usual options are either simple tube –only steering or use of introducers (such as bougies or custom-made metal introducers, e.g. Gliderite). When IDLs are not able to provide direct line of sight views of the laryngeal inlet, the tracheal tube still needs to be safely delivered into the field of vision. However, because this will inevitably also be relatively blind, tissue injury related to blind tube delivery is possible. This is a well-reported complication for Glidescope which is an example of a steering device. (An alternative description for steering devices is open path tube delivery devices.)

T point

The point in the median sagittal plane representing the mid-point of the internal surface of the mandible inter-condylar position. This point is important for the JIST model. In this model T was the most antero-inferior position of the airway behind the thyroid cartilage and above the vocal cords. For the purpose of this study a more obvious external equivalent was used, namely the cricothyroid membrane, which could be marked on the skin pre-operatively.

VAS score (Visual Analogue Scale)

VAS is a measurement instrument that tries to measure a characteristic that is believed to range across a continuum of values and cannot easily be directly measured. In this thesis the method was used to record Ease of Intubation and Ease of Laryngoscopy.

X-point

The point in the median sagittal plane where the lines IT and JS intersect. This point is important for the JIST model. For the photographic overlay technique, the conventional construction was reversed in that, following on from previous results, the X point was marked at two thirds of the way up from T on the line IT. This allows construction of the line JX, and hence the substitute S-point which was where the extended JX line makes contact with the anterior neck skin.

X-ray laryngoscopy

This term describes the imaging technique where a single lateral x-ray of the head and neck taken at the moment of maximal laryngeal exposure of the laryngeal structures with a laryngoscope. To optimize the use of this technique for research purposes the films are usually taken with fixed distances for the x-ray imaging and the head and neck maintained in a sagittal plane, with no rotation of the laryngoscope. (See also, JIST model)